ON LINE PROTECTION OF TRANSMISSION LINES USING MICROPROCESSOR

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Dedicated to

my mother

CERTIFICATE

Certified that this work 'ON LINE PROTECTION OF TRANSMISSION LINE USING MICROPROCESSOR' by V.P. Sunnak has been carried out under my supervision and has not been submitted elsewhere for a degree.

July 4,1983

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ABSTRACT

With the increase in complexity of power system network; the need for fast, efficient and reliable protection system has become a necessity. Protection schemes using electromechanical relays has numerous disadvantages and hence they were replaced in the beginning by electronic relays, then by solid state relays. Although these solid state relays are successful in operation, they have certain distinct disadvantages such as time of operation of relay is approximately 3-4 cycles, lack of flexibility and absence of self checking etc. These disadvantages have resulted in a trend towards the use of programmable equipment in place of hardwired systems.

The high speed clearance of fault on the complex power system network, very effectively improves the transient stability limit. The rotational kinctic energy introduced into a power system during a fault is proportional to the square of the fault clearance time. Therefore high speed clearance of faults close to large sources of generation will reduce the system acceleration move than any other form of dynamic control. The fault clearance time depend on the speed of protective relay as well as that of the associated

circuit breaker, the realisation of high speed protective relaying scheme has become imperative.

In this thesis, a review of various method using digital protection algorithms and design and development of microprocessor based on line protective relaying schemes for EHV/UHV transmission lines are outlined.

LIST OF FIGURES

LIST OF PRINCIPAL SYMBOLS

V_{pk} : Peak voltage

I_{pk} : Peak current

ω_1 : normal power frequency of 50 hertz

ω_2 : angular frequency corresponding to data window

V_d : direct axis component of voltage

V_g : quadrature axis component of voltage

I_d : direct axis component of current

I_q : quadrature axis component of current

A/D : Analogue to digital converter

S/H : Sample and Hold circuit

CPU : Central Processing unit

ROM : Read only memory

RAM : Random access memory

EPROM : Evaseable programmable read only memory

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

For the protection of EHV/UHV transmission line, a fast, sensitive, reliable, efficient and low cost protection scheme is necessary. The sensitivity and selectivity of a protective scheme depends upon the type of the relay unit employed. Of the several electromagnetic measuring units available, the induction cup unit proved to be the best in distance relaying applications because of its faster speed (3-5 cycles) and greater sensitivity compared to the other types of electromechanical relays and also its ability to produce any type of conventional threshold characteristics.

However, with the advent of solid state devices, such as semiconductor diodes and transistors, a trend towards employing them for relaying purposes, has emerged. The need for faster measuring unit gave impetus to the development of solid state (i.e. static) relays in the initial stages.

The merits of static relays are greater sensitivity, higher speed, lower (VA) burden, no contact problems and immunity from vibrations and shocks etc. due to external causes. The static relays are being used increasingly in recent years, specifically for the protection of EHV/UHV

transmission lines where increased sensitivity, reliability and speed are of importance.

The selectivity, provided by a protective relaying scheme, depend to a great extent upon the type of threshold characteristics obtained from the relay unit employed in it. The selectivity, between the internal and external fault, can be achieved by the use of multizone directional distance relaying scheme with or without carrier current pilot schemes. The selectivity, between internal faults and other abnormal conditions, such as power swing etc. depend upon the shape of the threshold characteristics. The quadrilateral characteristics has proved to be the best in fulfilling these requirements to the maximum extent. The high speed clearance of faults on the complex power system network very effectively improves the transient state stability limit i.e. the power transfer capability for a given stability limit. The rotational kinetic energy introduced into a power system during a fault is proportional to the square of the fault clearance time. Therefore, high speed clearance of faults close to large sources of generation will reduce the system acceleration more than any other form of dynamic control which can be used only after the system is being accelerated. In the recent years, this aspect of improving transient stability has been drawing the

attention of quite a few research engineers and organisations. The fault clearance time depends on the speed of the protective relays as well as on that of the associated circuit breakers [1], the realization of high speed protective relaying scheme has become imperative because high speed circuit breakers are available.

Digital protection schemes are well ahead in this direction since programmable equipments are of self checking nature and fast responding type. Using programmable equipment, it is possible to realize move complex characteristics with less complexity in logic. The use of digital computer for the protection of power system equipment is of recent origin, the first proposal appearing in late 1960's. Also, very recently there has been a trend towards employing micro-processor and multiprocessor for the power system protection purposes. Microprocessors provide programmable logic at low costs. This has led protection engineers to use micro-computer in protection and other related areas which traditionally are the domains of analog devices. All these factors gave rise to the motivation for developing a microprocessor based distance relaying scheme for the protection of EHV/UHV transmission lines.

1.2 OBJECTIVE AND SCOPE

The objective and scope of the work reported in this thesis have been:

a) To present a critical review of the important solid state relaying schemes reported so far for the protection of long and heavily loaded EHV/UHV transmission lines,

b) To present an overview of the digital computer relaying algorithm developed uptill now as well as the philosophy behind the existing and proposed algorithms, and

c) To present the design and development of the proposed microprocessor based protection schemes for the EHV/UHV transmission lines.

1.3 LITERATURE SURVEY

In the past, over current relays were being used for the protection of transmission lines. However, increasing demand in the use of electrical energy throughout the world has necessitated a corresponding increase in the transmission line voltage to enable to transfer move power economically and efficiently and also complexity of the power system networks, these overcurrent relays were found to be unsuitable because of several demerits such as, shifting

of balance point with the change of generation capacity, type of faults and also switching transients. Also, these over current relays can be used only on systems where the minimum fault current exceed, the maximum load current. However, the directional over current relays are still being used as back up relay for ground fault relaying. On account of the above mentioned drawbacks associated with the over current relays, the distance relays have been developed. A brief and critical review of the important literature pertaining to the evolution of distance relays, travelling wave relays, digital relays, using digital computer and microprocessor for the protection of transmission lines, is presented in the following sections.

1.3.1 Distance Relays:

Distance relays are used primarily for the protection of transmission lines and, as their name implies, they measure distance, i.e. they recognize faults occuring within the protected section of the line from the fact that the distance from the relay to the fault is less than the setting of the relay.

1.3.1.1 Electromechanical Relay:

In the evolution of relays for the protection of transmission lines, the electromechanical relays were

developed first and in that of distance relays the plain impedance relay was first one that was conceived and developed. In 1923, Crichton [2] reported about an impedance relay which employed an induction disc actuating structure and operated in a time proportional to the impedance between the relay and the fault point. In 1928, Mclaughlin and Erickson [3] reported about a directional impedance time relay built with an induction disc actuating structure. They presented the constructional details and described the principle of operation alongwith the technique for obtaining proper voltage for the restraining element. In 1944, Goldsborough [4] reported about a modified impedance relay built with a balanced beam structure and described how a circular pick up characteristic of any desired radii and with any desired location of the centre could be obtained. In 1928 the induction disc type reactance relay was designed by Warrington [5] and performance of normal and high speed reactance relay was published by George [6]. In 1933, Warrington [7] reported about a high speed reactance relay which was built with a four-pole induction cup actuating structure carrying current coils on one pair of opposite poles, and current and voltage coils on each of other poles.

Though the mho relay was first used in 1933 as the directional unit for an early type reactance relay [7], its

independent use for the protection of heavily loaded long transmission lines was first recommended in 1943 by Warrington [8] with its merits lucidly brought out. In 1944, Cordrey and Warrington [9] described its actual use in a carrier current scheme. Later, Hutchinson [10] described its use in a three step distance relaying scheme in which protection for zone 1 and 2 was provided by normal mho units and for zone 3 by an offset mho unit. In 1962, Skuderna [11] put forth the mathematical development of how offset conic and limacon characteristics could be obtained with a four pole induction cup structure.

1.3.1.2 Electronic Relay

In 1934, Wilderoe [12] presented electronic circuits, incorporating thyratron tubes, which were equivalent of many electromechanical relays in use at that time. In 1948, MacPherson and Warrington [13] described an electronic mho relay wherein instantaneous values of voltage and current inputs to the relay were compared at the instant of voltage input maximum. In 1949, Loving published electronic circuits for many protective functions, and presented experimental results. In 1954, Bergseth published a paper [14] describing an electronic directional distance relay which was insensitive to modern waveform distortion. However with the advent of solid state devices, the development of these electronic relays ceased.

1.3.1.3 Solid State Relays:

The first serious proposal, for employment of transistorised circuits for power system protective relaying, came from Adanson and Wedepohl [15] in 1956. In this, they presented a mathematical theory for determining the inputs necessary to obtain the directional, ohm, offset impedance and mho characteristics with a two input phase comparator. Several papers have appeared on solid state relaying using the approach of dual input comparator and multi-input cos and sine phase comparators. In 1970, Ramamoorty and Wani [16] reported about the fabrication and test results of a solid state quadrilateral distance relay.

In 1980, Parthasarthy et.al. [17] presented a new distance relay with an adaptive pick up characteristics which has narrow tripping area during power swing conditions and which automatically expands to large area during unbalanced faults. A solid state distance relay, employing, an operational amplifier chip as an amplitude comparator and producing elliptical characteristic, was developed by Ramamoorty et.al. [18].

1.3.2 Digital Relaying:

The use of digital computer, and microprocessors for protective relaying purposes has been engaging the attention of research and protection engineers since late 1960.

The first serious proposal for using digital computer came from Rockefeller [19]. The algorithms proposed so far, involves in the determination of fundamental frequency impedance to the fault point from the fundamental components of voltage and currents whichn are extracted from the complex post fault waveform by analogue and/or digital filters. Mann and Morrison [20] described the predictive calculation of peak values of and the phase angle between the voltage and current from much fewer number of samples. Several algorithms were developed subsequently and tried by Ranjabar et al. and others [26].

The possibility of utilising an on line microprocessor (micro-computer) to perform the protection, switching and data collections of EHV/UHV transmission system is attracting increased attention. Of these functions, on line protection is likely to be the most exacting in terms of microprocessor based hard wired facilities.

A directional over current relay using microprocessor was developed by A.K. Ghai [21]. The relay hardware, apart from a microcomputer, consists of simple digital circuits, current measurement is carried out with expensive analague to digital converter. G. Thirupathaiah etc. [22] described the technique of developing a relay having quadrilateral characteristics based on fundamental frequency signal.

Y. Akimoto et.al. [23] developed a digital current differential carrier relaying using microprocessor. In 1977, Yoshiteru Miki [24] realised Mho and reactance relay characteristics and thus gave a new dimension to protection engineers in the digital relaying field.

The results, so far reported on various protection schemes for EHV/UHV transmission lines based on microprocessor application, have been obtained by simulating it on either digital computer or INTEL 8080 based microcomputer.

1.4 SUMMARY OF THE WORK REPORTED IN THIS THESIS

The summary of the work carried out and reported in this thesis, is presented below chapterwise.

Chapter 2 starts with an overview of digital algorithms for protective relaying schemes of EHV/UHV transmission lines alongwith major philosophies used in designing digital relaying schemes.

Chapter 3 deals with the theory and mathematical formulation including the algorithm for the digital simulation of the proposed relaying schemes. Also, the software realization of the proposed relaying schemes are given in this chapter.

Chapter 4 deals with the design, development and testing of microprocessor based relaying schemes. Different types of digital protection systems based upon their hardware implementation have also been discussed.

Finally, the thesis concludes with Chapter 5, which highlights briefly the work reported in this thesis along with the discussion of the result and scope of further work in this field.

CHAPTER 2

DIGITAL PROTECTION OF TRANSMISSION LINE

2.1 SUMMARY

This chapter gives an overview of digital algorithms and systems for protective relaying schemes of EHV/UHV transmission lines. Major philosophies used in designing digital relaying schemes are outlined.

2.2 PRINCIPLE OF DIGITAL PROTECTION

The principle of digital protection as applied to transmission line is described by a block diagram of simplified hardware configuration as shown in Fig. 2.1. An analog input subsystem accepts 3-phase ac quantities from power system through conventional CT's and PT's. All of these quantities are sampled simultaneously at predetermined sampling rate, converted to digital form using Analog to digital converters and then transferred to the digital processor. The processor stores, organises and makes decisions based on the value of samples with reference to the programme stored in the memory of processor. The main purpose of the processor is to send the tripping command to circuit breaker for isolation of line on occurance of internal faults.

2.3 ADVANTAGES OF DIGITAL PROTECTION

The main advantages of digital protection are given below.

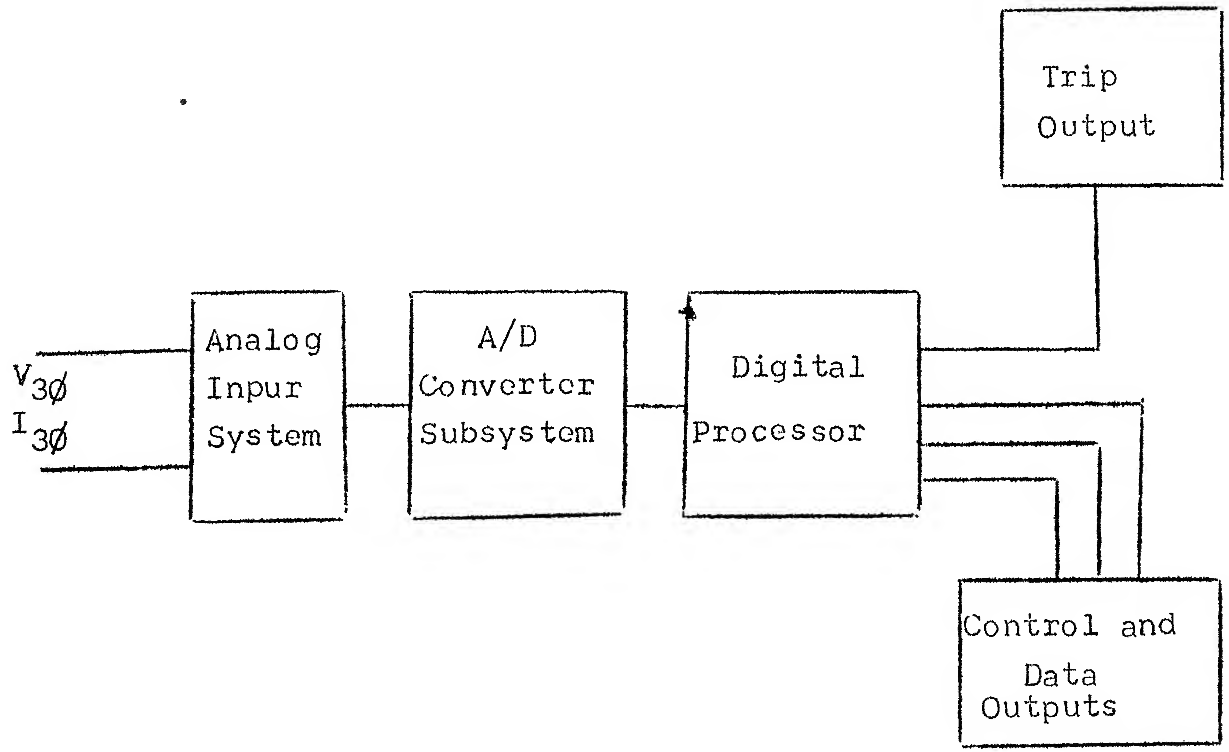


Fig. 2.1: Simplified Hardware Configuration

a) Possibility to realize sophisticated threshold characteristics of relays.

b) Easy to change the setting for alteration in system conditions.

c) Ability to check correctness of input and data missing or incorrect informations.

d) Interfacing with other controlling devices is possible.

e) It requires less maintenance

and f) It can give fault reports without specially designed devices, for post fault analysis.

2.4 DIGITAL TRANSMISSION LINE PROTECTION ALGORITHMS

Distance relays evaluate the line impedance by looking into the transmission line. The basic approaches being used in digital transmission line protection are of three types. These approaches depend on the form of the final input signal used to make the relaying decision. They are:

a) Transmission line protection based on system parameters.

b) Transmission line protection based on fundamental frequency signal.

c) Transmission line protection based on the signal containing both fundamental and transient frequencies.

2.4.1 Transmission Line Protection Based on System Parameters:

This assumes representation of a line by a set of differential equations. The most common model of a

transmission line is the one containing R and L as system parameters. The differential equation of this model is of the form,

$$v = Ri + L. \frac{di}{dt} \tag{2.1}$$

This representation of a transmission line recognises the DC offset as a valid part of the polution and, therefore, no special features have to be implemented to suppress the DC offset. Calculated value of R and L using equation (2.1) are used for phase-distance and ground-distance relaying schemes. The set of equations is manipulated depending upon the type of fault, and the final equation obtained is of the form of equation (2.1), but actually contains some combination of current and voltage phase value to form v and i given in equation (2.1).

A number of algorithm have been suggested [43] to solve equation (2.1) numerically. In 1971, McInnes et al. [25] proposed an algorithm for this purpose. It proposed integration of equation (2.1) over two successive time periods so that a sufficient number of equation are obtained to solve for R and L. Integrals are evaluated numerically using trapezoidal rule and the final expression for R and L are of the form,

$$R = \frac{(v_{k-1}+v_k)(i_{k-1}-i_{k-2})-(v_{k-1}+v_{k-2})(i_k-i_{k-1})}{(i_{k-1}+i_k)(i_{k-1}-i_{k-2})-(i_{k-1}+i_{k-2})(i_k-i_{k-1})} \tag{2.2}$$

$$L = \frac{(v_{k-1}+v_{k-2})(i_{k-1}+i_k)-(v_{k-1}+v_k)(i_{k-1}+i_{k-2})}{(i_{k-1}+i_k)(i_{k-1}-i_{k-2})-(i_{k-1}+i_{k-2})(i_k-i_{k-1})} \times \frac{h}{2} \tag{2.3}$$

where v and i are instantaneous value of voltage and current, k is the instant and h is the time interval.

However, it should be noted that, there are several problems, associated with the characteristics of actual transmission line which are not accounted in equation (2.1). This equation assumes perfectly transposed transmission line, and neither the shunt capacitance nor the capacitance used for series compensation is considered in this case. The fault resistance and effect of power flow on the line at the instant of fault are also not considered.

A number of techniques can be developed to cope with some of the problems mentioned above. Of course, a quite powerful technique is to filter the input signal with a low pass filter, which enables the attenuation of the high frequency transients which are introduced by some of the effects mentioned above.

In 1975, Ranjbar et al. [26] developed another technique which relates appropriate integration interval of equation

(2.1) to the particular harmonics that are selected for removal. The sampling rate is related as a multiple of the order of the harmonic to be removed, which makes the procedure quite restrictive by the sampling rate selection and accuracy.

If a transmission line is represented by a single PI section, then an algorithm can be developed which will accommodate both the DC offset as well as high frequency transient componentsof the input signals without any additional filtering. In this case, the computational burden is increased, but when this algorithm is compared to an algorithm with the low-pass filtering procedure, then the overall computational burden of the two algorithms are not very different.

2.4.2 Transmission Line Protection Based on Fundamental Frequency Signal:

This relies on the theory of orthogonal transform [27]. The most widely used is the Fourier transform theory which utilizes the set of sine and cosine functions as an orthogonal set. Any function, then, can be represented as a sum of the combinations of the functions from the defined orthogonal set. Basic properties of the Fourier transform can be used to extract any particular frequency component from the incoming signal. The expression derived can be based on either

continuous or on the discrete Fourier transform. In the case of the continuous functions, some form of numerical approximation is done to obtain a digital solution. Ramamoorty [28] correlated samples of the input signals (voltage and current) with the stored samples of reference fundamental sine and cosine waves.

If the expressions of the waveforms are given in rectangular form, then the general expressions for the sine and cosine component of voltage for sample point k are given as [29],

$$V_s = \frac{1}{N} [\ 2 \sum_{\ell=1}^{N-1} V_{k-N-1} \sin (\frac{2\pi}{N} \ell)] \tag{2.4}$$

$$V_c = \frac{1}{N} [V_{K-N} + V_K + 2 \sum_{\ell=1}^{N-1} V_{K-N+1} \cos (\frac{2\pi}{N} \ell 1) \tag{2.5}$$

where V_i are the voltage samples and N is the number of samples taken per fundamental cycle and 1 is variable.

From Eqs. (2.4) and (2.5) we get the expression for voltage

$$V = [\ V_s^2 + V_c^2\ ]^{1/2} \tag{2.6}$$

and the phase angle is given by

$$\phi_v = \tan^{-1} (V_s/V_c) \tag{2.7}$$

Similarly for current signal,

$$I = [I_s^2 + I_c^2]^{1/2} \tag{2.8}$$

and

$$\phi_I = \tan^{-1} (I_s/I_c) \tag{2.9}$$

Finally, the expression for the impedance is,

$$Z = |Z| \angle \phi_z \tag{2.10}$$

where,

$$Z = \left[\frac{V_s^2 + V_c^2}{I_s^2 + I_c^2} \right]^{1/2} \tag{2.11}$$

$$\phi_z = \tan^{-1} (V/I) \tag{2.12}$$

If the calculated value of Z and ϕ_z using equations (2.11) and (2.12) exceed the setting, this determines the relaying action. This comparison can be used to perform distance impedance relaying function.

It should be noted that, theoretically, this method promises the best accuracy because it utilizes the fundamental components only and all other components are rejected. This, of course, assumes that the data are available for full power cycle. To improve the time response of the algorithm is to reduce the data window to one half of a cycle [30], which changes the limit on the expressions(2.4) and (2.5).

This introduces additional error due to DC offset and high harmonics, but the scheme can be made quite acceptable by using various methods for compensation of error sources [30]. The one half cycle scheme is particularly efficient computationally when 12 samples per cycle are used because of certain symmetries of the fourier coefficients. A sinusoidal curve fit could be performed where incoming data are used directly to calculate the apparant resistance and reactance to the fault. Samples of voltages and currents are used to perform the fundamental sinusoidal component fit [31]. Similar methods can be applied to calculate peak value of voltage and current [32] as well as power flow, which can then be used to perform relaying function.

2.4.3 Transmission Line Protection Based on the Signal Containing both Fundamental and Transient Frequencies:

This scheme employs two basic techniques. One assumes that the signal can be modeled with an expression containing both fundamental signal and high frequency components. The assumed expression contains unknown parameters which can be determined by a least square estimation technique. Incoming samples are used for the fitting process. Yet another technique uses waveforms which are obtained directly from the transmission lines and contains high frequency components. These are travelling waves which can be obtained as a

solution of distributed parameter (differential) equation used as transmission line model.

The least square technique can be applied to obtain fairly good estimates, assuming a waveform which contains both decaying DC offset and harmonic components [33]:

$$K_1 e^{-\lambda t} + \sum_{m=1}^{N} [K_{2m}\sin(m\omega t)+ K_{2m+1}\cos(m\omega t)] \tag{2.13}$$

where K_1, K_2.... K_{2N+1} are unknown parameters, N is the number of harmonics to be considered, λ is the decay constant of the offset and ω is the angular frequency.

Then the least square fit involves minimization of the expression

$$E = \int_0^T I-K_1 e^{-\lambda t} - \sum_{m=1}^{N} [K_{2m}\sin(m\omega t)+K_{2m+1}\cos(m\omega t)]^2 \tag{2.14}$$

where I is the waveform to be analyzed and T is the sampling period. The solutions of the minimization procedure are the unknown parameters K_r, r = 1,2,...2N+1. It should be noted that least square technique mentioned above are computationally quite involved and their accuracy is dependent on the data window applied as well as on the number of samples per cycle [29].

The travelling wave method usesas the basic model the well known telegraph equation (known as wave equation for lossless line) for distributed parameter transmission line

$$- \frac{\partial v}{\partial x} = L \frac{di}{dt} \qquad (2.15)$$

$$- \frac{\partial i}{\partial x} = C \frac{dv}{dt} \qquad (2.16)$$

Solution of the above equations are of the form

$$v(x,t) = \phi^{+} (x-\alpha t)-Z\phi^{-} (x+\alpha t) \qquad (2.17)$$

$$i(x,t) = \phi^{+} (x-\alpha t)+ \phi^{-} (x+\alpha t) \qquad (2.18)$$

where L is the series inductance per unit length, C is the shunt capacitance per unit length, $Z = (L/C)^{1/2}$ the line surge impedance and $\alpha = (LC)^{-1/2}$ the velocity of propogation. The function ϕ^{+} and ϕ^{-} represent travelling waves which moves in the positive and negative directions respectively. However, a number of techniques are developed for operation of relay.

One approach can be based on detection of the instantaneou change in voltage and current signal at the moment of fault. A particular discriminant function can be developed which is invariant with respect to the location of fault relative to the relay terminals.

2.5 DISCUSSIONS ALONG WITH CONCLUDING REMARKS ON RELAYING ALGORITHMS

Comparison of the line protection algorithm has been done on a very limited scale and there is only one study that gives reasonably extensive results[29]. It was concluded [29] that, in general, any of the algorithms is perfectly accurate when the assumptions from which it is generated are considered. However, the algorithms that are based on the gross and simple assumptions about the faulted waveforms are least accurate. Also, generally, the smaller the data window is, the larger the errors are. Finally, the differential equation algorithms performed quite accurately after approximately one half of a cycle of data used. The Fourier transform algorithms are the most accurate after one cycle of the available data. The travelling wave algorithms have very quick response down to several milliseconds and are quite accurate, particularly when data are obtained from both terminals of the line.

In this thesis, the algorithms used for the proposed digital transmission line protection schemes using Microprocessor, are based on:

a) Predictive calculation of peak value (voltage and current).

b) Extraction of the fundamental component using Fourier transform techniques taking data window equal to one-half the power cycle.

CHAPTER 3

MICROPROCESSOR BASED PROPOSED RELAYING SCHEMES

3.1 SUMMARY

In this chapter, the proposed methods based on two different approaches for impedance calculation for distance type protection suitable for on-line microprocessor protection of transmission lines are outlined. The software realisation of the schemes along with the computation times for implementation in real time are also given.

3.2 PROPOSED RELAYING SCHEME BASED ON THE PREDICTIVE CALCULATION OF PEAK FAULT CURRENT AND VOLTAGE

The method of transmission line protection in this scheme is based on predictive calculation of peak fault current and voltage from small number of samples. The peak values of current and voltage are estimated numerically, from these the transmission line impedance is calculated and fault condition detected.

3.2.1 Mathematical Formulation

The method of calculation of line impedance involves the predictive calculation of peak current and peak voltage, the impedance being determined by division of peak voltage by peak current [20]. A digital computer sampling , a sinusoidal waveform, can determine the peak as they occur.

However, it is necessary in the interest of time to determine the peak value before their occurance i.e. to predict the peak value of the waveform from the given samples.

Let us consider a sinusoidal function,

$$v = V_{pk} \sin\omega t \tag{3.1}$$

where V_{pk} is the unknown (peak voltage) quantity and v is a typical sample value, ωt is also unknown. Taking the derivative of(3.1)w.r.t. time we get,

$$v' = \omega V_{pk} \cos \omega t \tag{3.2}$$

where v' is determined using the numerical technique as detailed in appendix C.

From the equation (3.2) we get,

$$\frac{v'}{\omega} = V_{pk} \cos\omega t \tag{3.3}$$

Squaring eqs. (3.1) and (3.3), and adding we get,

$$V_{pk}^2 = (v)^2 + (\frac{v'}{\omega})^2 \tag{3.4}$$

Dividing equation (3.1) by eq. (3.3) we get,

$$\frac{v\omega}{v'} = \frac{V_{pk} \sin\omega t}{V_{pk} \cos\omega t}$$

$$\tan\omega t = \frac{v\omega}{v'}$$

$$\omega t = \tan^{-1} [\frac{v\omega}{v'}]$$

Thus point on cycle of voltage sample

$$V_\theta = \text{arc tan } [\frac{v\omega}{v'}] \quad (3.5)$$

Similarly for the current, we can get (refer to the eq.(3.4)),

$$I_{pk}^2 = (i)^2 + (\frac{i'}{\omega})^2 \quad (3.6)$$

$$I_\theta = \text{arc tan } [\frac{i\omega}{i'}] \quad (3.7)$$

Impedance is calculated by dividing the equation (3.4) by the equation (3.6) and hence we get,

$$Z^2 = \frac{V_{pk}^2}{I_{pk}^2} \quad (3.8)$$

Angle of impedance is obtained by subtracting equation (3.7) from the equation (3.5); hence, we get,

$$Z_\theta = V_\theta - I_\theta \quad (3.9)$$

The possible existence of an exponentially decaying d.c. transient on the current and voltage signal of a high voltage system is not taken into account in the impedance calculation as the offset d.c. component is negligible because if an ideal CT (having mimic impedance) connected to a secondary burden having the same X/R ratio as the primary circuit, then the voltage across the burden will be purely sinusoidal [47]. However, exact cancellation of d.c. offset is not possible for all faults. The primary X/R ratio to be matched

is that of source plus transmission line upto the fault point, and since, in general, the source X/R is not equal to the line X/R, the overall primary X/R is a variable quantity, dependent on how far along the line the fault occurs. This problem can be avoided by matching the secondary burden to the primary X/R composed of the source plus, say 90% of line impedance. It is for faults near the end of the line (i.e. near the balance point) that the most accurate impedance calculations are required for discrimination purposes and for these faults, the transient component will be almost completely removed. For faults closer in, offset will be drastically reduced but not entirely removed.

Sampling rate is a variable, but it has been taken in this case, as 40 samples per cycle, i.e. 0.5 ms between two samples, as this gives a maximum error, in V_{peak} at t_o on a 50 Hz system, of 0.15 percent (refer appendix B for details). This shows that numerical errors are at least small in theory.

3.2.2 General Principle of Relay for Phase Faults:

The principle used in the proposed protective scheme for phase faults is that once the disturbance in impedance is detected, the type of fault (phase or ground) is determined and a suitable single phase relaying quantities such as voltage and current are chosen for impedance calculation. Two continuous signals, one line to line voltage or line to

ground voltage and line current are sampled sequentially at predetermined sampling rate i.e. 40 samples per cycle.

Fault detection is performed by comparing the latest voltage sample to the corresponding sample of the previous cycle. If the value differs in excess of a tolerance limit 5%, the counter is incremented. If the value of the counter is equal to five, the routine jumps to fault detection zone. If the comparision of the voltage samples yield a difference less than above tolerance,
the counter is decremented, if it is not already zero.

3.2.3 Calculation of Impedance:

On occurance and subsequent detection of fault, the program calculates voltage and current derivatives and finally, calculate the V_{peak}, I_{peak}, impedence and angle of impedance using the equations (3.4) - (3.9).

3.2.4 Software Realisation:

In the proposed relaying scheme for phase faults, a RESTRICTED MHO characteristics has been realized and simulated on intel 8080 microcomputer taking 40 samples per cycle.

For testing on Microcomputer, data has been generated using symmetrical component for the sample power network as given in the Appendix D. The algorithm used to simulate

the proposed scheme for phase faults is given below in sequence.

1. Intialize all the registers of CPU, counters etc.
2. Store the constants pertaining to relay characteristics such as set impedance, look up table for arctan.
3. Take samples.
4. Cycle by cycle comparision of voltage samples is carried out and accordingly, the counter is incremented, if, the difference in the two voltage samples is more than the specified value or otherwise decremented, if not, already zero. If the value of the counter is move than 5, fault determination starts, else go to step 3.
5. Calculate derivatives of voltage and current using numerical technique given in Appendix C.
6. Calculate V_{peak} and I_{peak} using equations(3.4) and (3.6)
7. Calculate the impedance using equation (3.8) and determine argument of impedance from the look up table of arc tan stored in the memory.
8. Check whether $0 < Z_{\theta} < 90$ else go to step 3.
9. Check whether $Z_R \cos(\phi-\theta) \geq Z_c$, else go to step 3.
10. Initiate tripping signal.

The sampling is continued throughout the calculation stage and the samples are stored in the appropriate memory location by hardware arrangement discussed in the section later.

3.2.5 Results alongwith Discussions:

1. With the proposed algorithm the estimation of V_{peak} and I_{peak} are accurate to $\pm$ 09%, the impedance modulus to within $\pm$ 10% and argument of impedance to within 5°. Fig. 3.1 shows the characteristic of proposed algorithm, which is obtained by keeping angle ϕ of Z_R fixed and for a particular angle of fault impedance, the impedance is found out where the tripping occurs and the theoretical characteristics from where it is seen that the actual characteristics is very near to the theoretical one.

2. The operating time of the proposed relaying scheme for phase faults is approximately equal to 4.44ms for zone 1 operation, 15.18 ms for zone 2 operation and 25.44ms for zone 3 operation, which are sum of

a) time required to acquire 5 samples for detection of disturbance which is 2.0 ms

b) time required for calculation of impedance and angle of impedance and computation time required to satisfy restricted Mho characteristics which is 1 8-7 cycles (2.44ms) for zone 1, 13438 cycles (2.68ms) for zone II operation, 14701 cycles (2.94ms) for zone III operation

3. Timing details at various stages is given in the flow chart. (See Fig. 3.2).

4. The program listing is attached in Appendix E.

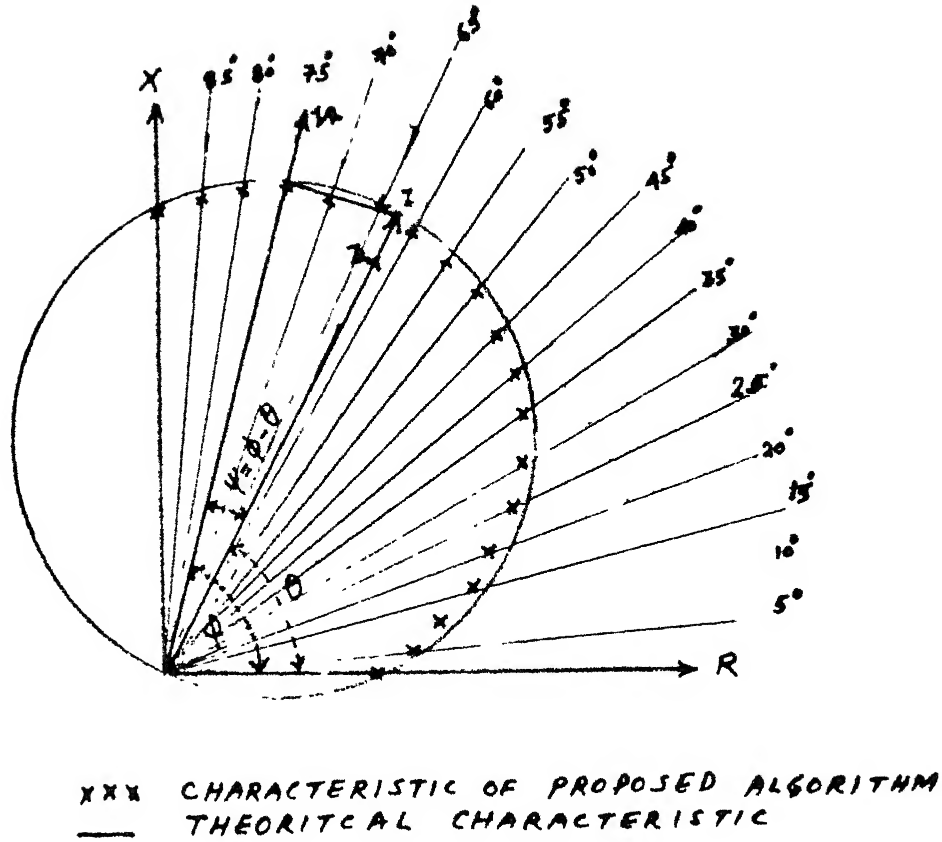


FIG3·1 RESTRICTED MHO'S RELAY CHARACTERISTIC

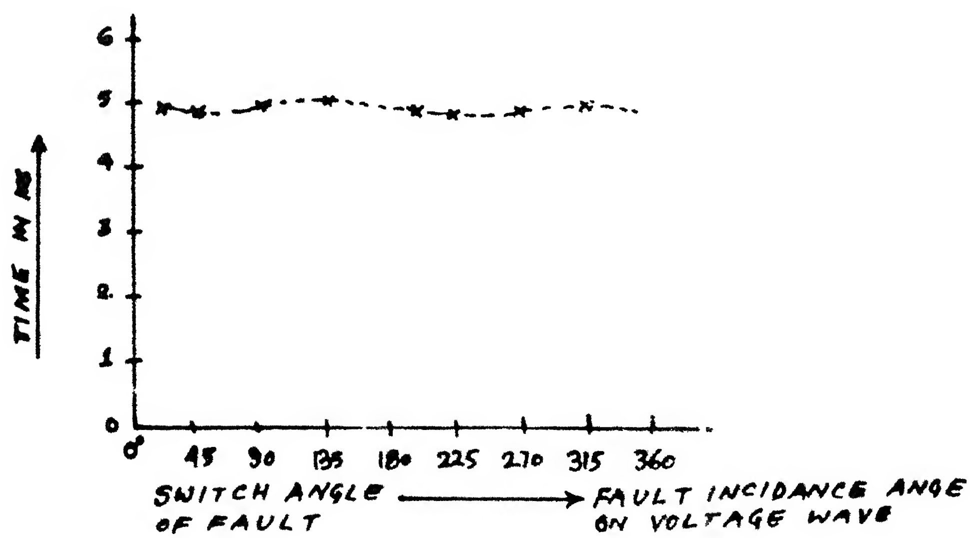


FIG3·2A: OPERATING CHRACTERISTIC OF R. MHO RELAY

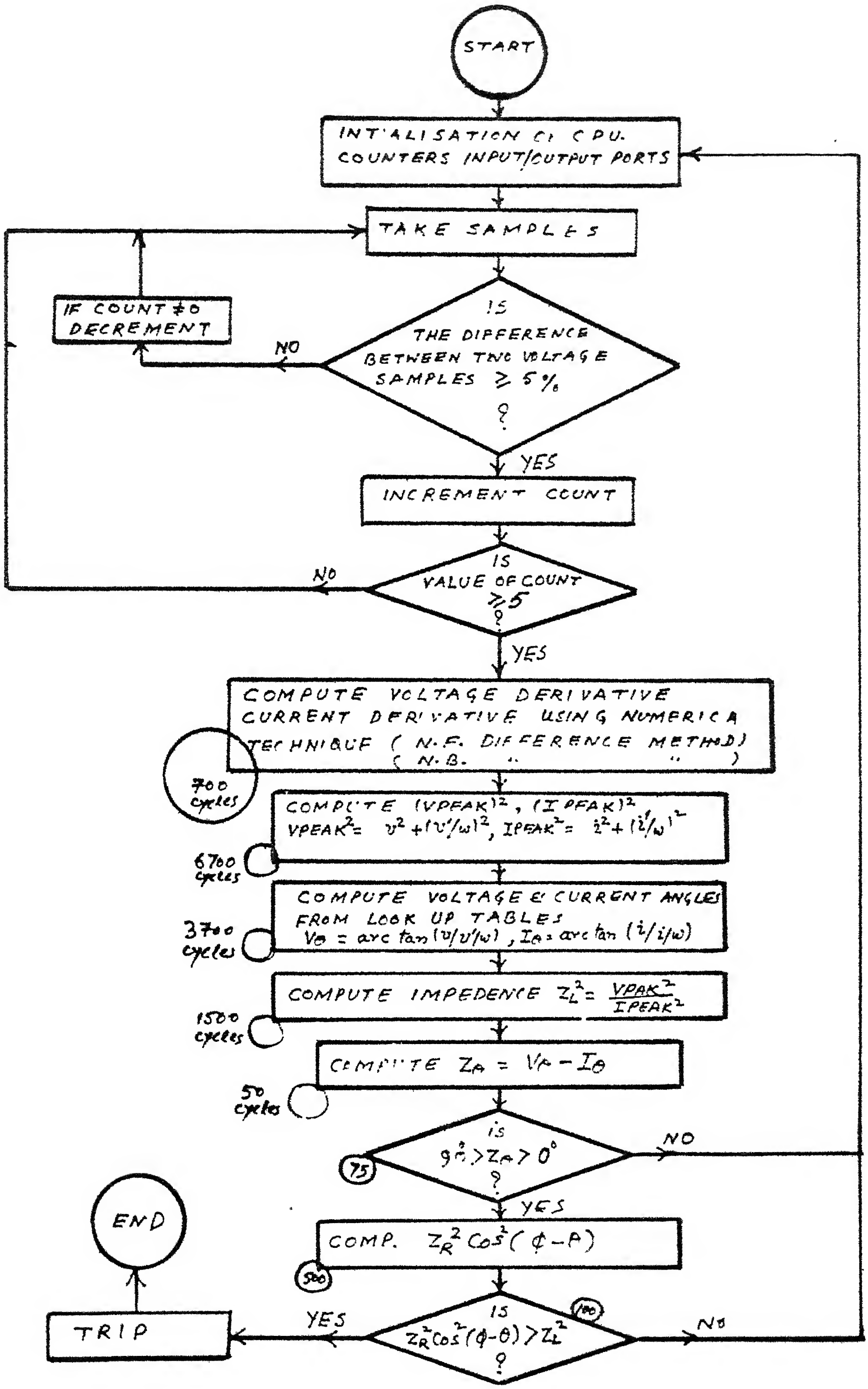


FIG 3.2: FLOWCHART: PROPOSED REAL TIME ALGORITHM FOR RESTRICTED MHO CHARACTERISTIC

5. The complexity of calculation has been reduced by converting the essentially parallel operation of analogue relays into serial digital computations. Also no data from healthy phases is involved in the calculation of impedance. This has necessitiated the development of a protective scheme which, upon detection of a disturbance, isolates the phase involved and selects an appropriate set of relaying current and voltage for subsequent impedance calculation.

6. The operating time vs switch angle of fault current is given in Fig. 3.2A.

3.3 PROPOSED RELAYING SCHEME BASED ON FUNDAMENTAL COMPONENT TAKING DATA WINDOW EQUAL TO ONE-HALF POWER CYCLE

The proposed relaying scheme is based on the extraction of fundamental frequency component from the input signal, using Fourier transform theory and assuming that data are available for half of the power cycle.

3.3.1 Mathematical Formulation:

Distance fault locating digital algorithms are often based on the processing of fundamental components which are contained in the currents and voltages. If the extraction of these components is done by means of correlating the signal with sine and cosine function of the fundamental frequency, and the data window is shorter than one cycle, the

presence of aperiodic components in the signal gives rise to large error. To minimise the error in calculating the fundamental component for a data window equal to half cycle, the signals ought to be correlated with sine/cosine functions which have periods equal to the data window length [34].

Let current and voltage input signals are represented by,

$$I_{(t)} = I_1 \cos(\omega_1 t - \alpha) + I_a\, e^{-t/\tau_a} + I_p\, e^{-t/\tau_p} \cos(\omega_p t - \gamma) \tag{3.10}$$

$$V_{(t)} = V_1 \cos(\omega_1 t - \alpha + \varphi) + V_a\, e^{-t/\tau_a} + V_p\, e^{-t/\tau_p} \cos(\omega_p t - \beta) \tag{3.11}$$

First terms of the right hand side of the equations (3.10) and (3.11) are steady state fundamental components. The second terms are well known aperiodic (i.e. DC) components decaying with time constant τ_a which to a certain degree random factor like for example, a fault resistance. The third term represents decaying oscillations induced by the fault. The decaying time constant τ_p varies and has been assumed to be equal to infinity, being the worst case. Amplitude of transient components depend on the nature of signal and, it is the transient components, which make the greatest source of error in the process of fault location. When the

data window is less than one period, the transient component becomes higher, thus increasing the overall error substantially. Therefore, the real and imaginary parts of voltage and current is calculated for the angular frequency of ω_2 correspondin to data window at which the spectrum of aperiodic component reaches minimum.

The real and imaginary parts of fundamental component of voltage and current are,

$$V_1 = V_d + jV_q \tag{3.12}$$

$$I_1 = I_d + jI_q \tag{3.13}$$

Since the signal is being processed in certain time span T_ω , called data window, the shifted time scale is introduced into the formula of signal. This makes the middle of the window always coincide with 0 of the new time variable τ.

Let, $\tau = t - (t_1 + \frac{T_\omega}{2})$ where t_1 is the begining of the data window.

According to Fourier transform theory and correlating the signal with sine/cosine functions which have period equal to data window T_ω i.e. $\omega_2 = \frac{2\pi}{T_\omega}$, we have,

$$V_d = \frac{K}{T_\omega} \int_{t_1}^{t_1+T\omega} V_{(\tau)} \cos \omega_2\tau \; d\tau \tag{3.14}$$

$$V_q = \frac{P}{T\omega} \int_{t_1}^{t_1+T\omega} V_{(\tau)} \sin \omega_2\tau \quad d\tau \tag{3.15}$$

$$I_d = \frac{K}{T\omega} \int_{t_1}^{t_1+T\omega} I_{(\tau)} \cos \omega_2\tau \quad d\tau \tag{3.16}$$

$$I_q = \frac{P}{T\omega} \int_{t_1}^{t_1+T\omega} I_{(\tau)} \sin \omega_2\tau \quad d\tau \tag{3.17}$$

where coefficients K and P [34] are

$$K = \frac{\pi(1-r^2)}{r\sin\pi r}$$

$$P = \frac{-\pi(1-r^2)}{\sin\pi r}$$

and $\quad r = \dfrac{\omega_1}{\omega_2}$

ω_1 = normal power frequency of 50 hertz

ω_2 = angular frequency corresponding to data window.

Taking data window equal to half the period i.e. half cycle, i.e., $T\omega = \pi/\omega_1$, the coefficient K and P can be written as,

$$K = \frac{3\pi}{2} \quad , \quad P = -\frac{3\pi}{4} \tag{3.18}$$

Equation (3.14) to equation (3.17) can be written as,

$$V_d = \frac{3\pi}{2T\omega} \int_{t_1}^{t_1+T\omega} V_{(t)} \cos \omega_2(t-t_1-\frac{T\omega}{2}) \ dt \tag{3.19}$$

$$V_q = \frac{-3\pi}{4T\omega} \int_{t_1}^{t_1+T\omega} V_{(t)} \sin \omega_2 (t-t_1- \frac{T\omega}{2})dt \qquad (3.20)$$

$$I_d = \frac{3\pi}{2T\omega} \int_{t_1}^{t_1+T\omega} I_{(t)} \cos \omega_2 (t-t_1- \frac{T\omega}{2})dt \qquad (3.21)$$

and,

$$I_q = \frac{-3\pi}{4T\omega} \int_{t_1}^{t_1+T\omega} I_{(t)} \sin \omega_2 (t-t_1- \frac{T\omega}{2})dt \qquad (3.22)$$

The solution of the above equations (3.19-3.22) have been obtained using numerical techniques as given in the Appendix A and the final results obtained are as shown below.

$$V_d = A[V_{(t_1)} \cos\pi - 2V_{(t_2)} \cos\frac{2\pi}{N} - 2V_{(t_3)} \cos\frac{4\pi}{N} -$$

$$\cdots - 2V_{(tN)} \cos\frac{(N-1)2\pi}{N} + V_{(tN+1)} \cos\pi]$$

$$V_q = A[V_{(t_1)} \frac{\sin\pi}{2} + V_{(t_2)} \sin\frac{2\pi}{N} + V_{(t_3)} \sin\frac{4\pi}{N} +$$

$$\cdots + V_{(tN)} \sin\frac{(N-1)2\pi}{N} - V_{(tN+1)} \frac{\sin\pi}{2}]$$

$$I_d = A[I_{(t_1)} \cos\pi - 2I_{(t_2)} \sin\frac{2\pi}{N} - 2I_{(t_3)} \sin\frac{4\pi}{N} -$$

$$\cdots - 2I_{(tN)} \cos\frac{(N-1)2\pi}{N} + I_{(tN+1)} \cos\pi]$$

$$I_q = A[I_{(t_1)} \frac{\sin\pi}{2} + I_{(t_2)} \sin\frac{2\pi}{N} + \sin\frac{4\pi}{N} +$$

$$\cdots + I_{(tN)} \sin\frac{(N-1)2\pi}{N} - I_{(tN-1)} \sin\frac{\pi}{2}] \qquad (3.23)$$

where N is the number of intervals a over a sampling period.

3.3.2 Fault Locating Algorithm:

The impedance seen by the relay is obtained by dividing the peak of voltage by the peak of current i.e. the expression for the impedance is,

$$Z = \frac{V_d + jV_q}{I_d + jI_q}$$

$$= \frac{(V_d+jV_q)(I_d-jI_q)}{(I_d+jI_q)(I_d-jI_q)}$$

$$Z = \frac{V_dI_d+V_qI_q}{I_d^2 + I_q^2} + j\,\frac{V_qI_d-V_dI_q}{I_d^2 + I_q^2} \tag{3.24}$$

But, $Z = R + jX$

Therefore, we get,

$$R = \frac{V_dI_d+V_qI_q}{I_d^2 + I_q^2}$$

$$X = \frac{V_qI_d-V_dI_q}{I_d^2 + I_q^2} \tag{3.25}$$

3.3.3 Principle of Relay Operation for Phase Faults:

The principle underlying the proposed scheme is, that, the two continuous signals one, line to line voltage or line to ground voltage and second, line current are sampled sequentially at a predecided sampling rate, say 12 samples per cycle.

Fault detection is performed by comparing the latest voltage sample to the corresponding sample of the previous cycle. If the values differ in excess of a tolerance limit 5%, the counter is incremented. If the value of the counter is equal to seven (in this case) the routine jumps into the fault determination routine (see flow chart).

If the comparision of the voltage samples yield a difference less than 5% i.e. comparison is healthy, the counter is decremented, if it is not already zero.

3.3.4 Calculation of Resistance and Reactance:

On detection of disturbance i.e. when counter value is equal to seven (for the present case), the program starts calculating R and X using the equation (3.25) and finding whether the fault has occured or not. The incoming signals during this period are stored in the appropriate memory locations.

3.3.5 Software Realisation:

Since quadrilateral characteristics is the best threshold characteristic available for the protection of EHV/UHV heavily loaded long lines as it encloses the fault area compactly and therefore, possesses the valuable properties of least tendency for maloperation under heavy power swings and also greatest immunity to under reaching

tendencies arising out of fault resistance. In the proposed relaying scheme for phase faults, a quadrilaterial characteristics has been realized and simulated on INTEL 8080 microcomputer at IIT Kanpur taking 12 samples per cycle i.e. 6 samples per half cycle as data window is taken as half the power cycle (i.e. $T\omega = 1/2\ T_1$).

For testing on microcomputer, data has been generated using symmetrical components (see Appendix D , for sample power system network as given in the appendix D).

The algorithm used to simulate the proposed relaying scheme for phase faults is given below with reference to the flow chart.

1. Initialize all the register of CPU, counters etc.
2. Store the constant pertaining to relay characteristics such as sine and cosine table, K_1, K_2.
3. TAKE SAMPLES
4. Cycle by cycle comparison of voltage sample is carried out and accordingly by the counter is incremented if difference between two voltage sample is more than specified value or otherwise decremented if not already zero. If the value of counter is more than seven, fault detection starts, else Go to Step 3.
5. Calculate V_d, V_q, I_d and I_q using the equation (3.17-3.22) developed for data window $T\omega$ equal to half the power cycle.
6. Calculate R and X using equation (3.25).

7. Check whether $X \geq 0$ if YES continue else go to step 3.
8. Check whether $R \geq 0$ if YES continue else go to step 3.
9. Check whether $R \leq R_3$ if YES continue else go to, step 3.
10. Check whether $R \leq R_2$ if YES continue else go to step 13.
11. Check whether $R \geq R_1$ if YES continue else go to step 14.
12. Initiate the tripping signal
13. Check whether $K_4 \geq K_2$ if YES go to Step 12 else go to step 3.
14. Check whether $K_3 \leq K_1$ if YES go to step 12 else go to step 3.

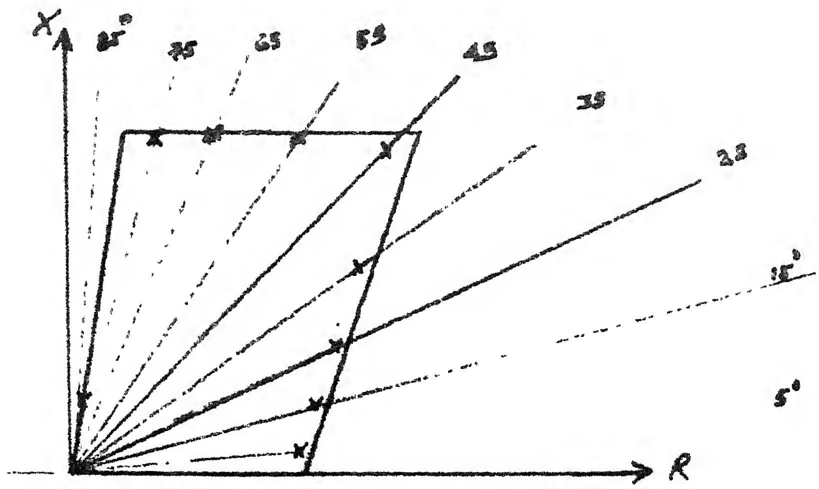
3.3.6 Results and Discussions:

1. Since numerical integration is used and there is error in calculating R and X Fig. 3.3. shows the characteristics of the proposed algorithm and the theoretical characteristic, from where it can be seen, that the proposed characteristic is very close to the theoretical one.

2. The operating time of proposed relaying scheme for phase fault is approximately equal to 16.23 ms for Zone 1, 21.62 ms for Zone 2 and 26.85 ms for Zone 3, which is sum of the

a) time to acquire necessary data i.e. in this case it is 10 ms.

b) time required for calculation of R and X and computing time required to satisfy quadrilateral characteristic which is in our case is 31026 cycle, for zone 1, 33125 cycle for zone 2 operation, 34255 cycle for zone 3 operation



xx CHARACTERISTIC OF PROPOSED ALGORITHM
— THEORTICAL CHARACTERISTIC

FIG 3·3 : QUADILATERAL CHARACTERISTIC OF THE PROPOSED RELAYING SCHEME

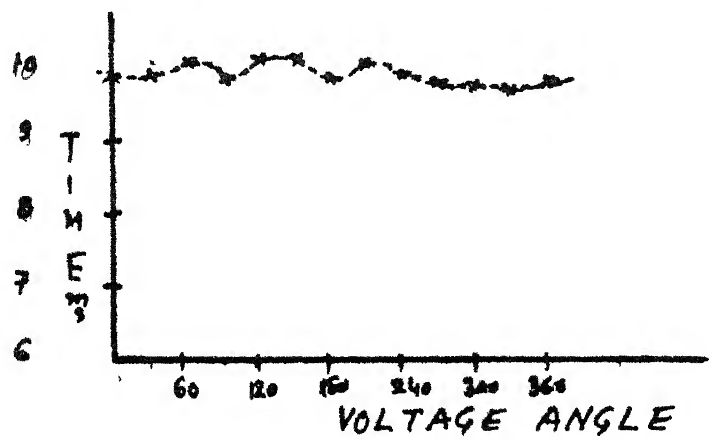


FIG 3·3A: OPERATING CHARACTERISTIC

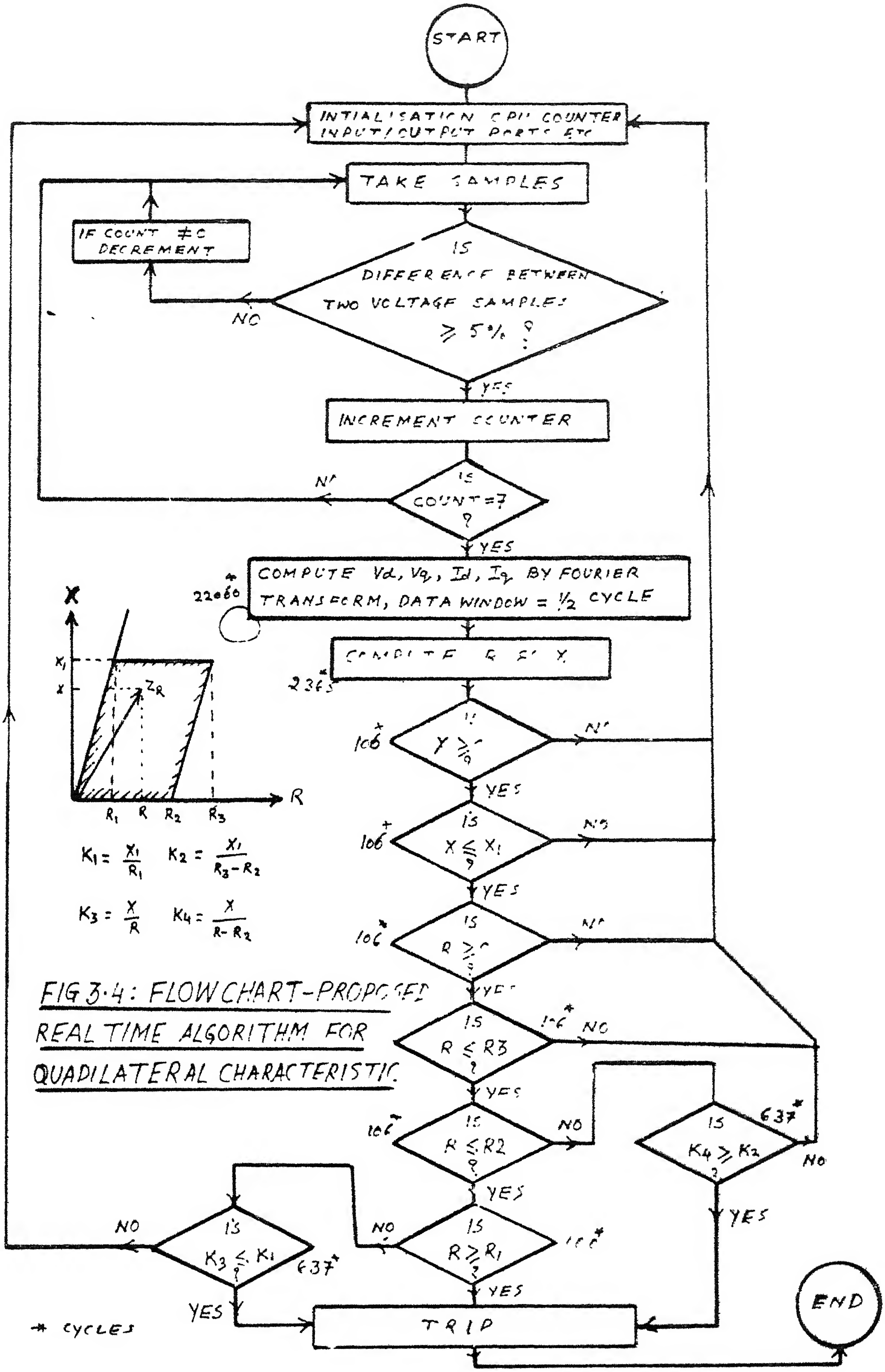


FIG 3·4: FLOWCHART-PROPOSED REAL TIME ALGORITHM FOR QUADILATERAL CHARACTERISTIC

3. Various calculation time is given in the flow chart. (See Fig. 3.4).

4. The program listing is attached as Appendix F.

5. The operating characteristic plotted between operating time and fault incidence angle is given in Fig. 3.3A.

CHAPTER 4

HARDWARE REALISATION OF PROPOSED RELAYING SCHEMES FOR ON LINE PROTECTION OF TRANSMISSION LINES USING MICROPROCESSOR

4.1 SUMMARY

This chapter deals with the design, development and testing of microprocessor based relaying scheme. The decentralized approach has been used for the hardware realization of the proposed relaying scheme as outlined in the previous chapter.

4.2 DIGITAL RELAYING SCHEMES

Based on the hardware implementation, we can divide the protection system developments into three categories.

a) Centralized approach

b) Decentralized approach

c) Integrated approach

4.2.1 Centralized Approach:

It covers implementation which uses only one mini-computer to accomodate most of the protection systems. The first digital relaying (prototype) system PRODAR 70, was developed in joint effort by Pacific Gas and Electric Company and the Westinghouse Electric Corporation in 1971 [35]. The system was minicomputer-based and all of the basic

protection functions found in a typical high voltage substation were implemented. For several years,a number of tests were conducted and the results were published in 1975 [36]. Also in the early 1970s, the American Electric Power Service Corporation (AEP) initiated a joint project with the IBM corporation to develop a minicomputer-based relaying and data acquisition system. This project resulted in a prototype system which was field tested and the results were published in 1976 [30]. In 1973, the General Electric Company (GEC) started a project to develop a minicomputer based distance relay, which was further extended to include a pilot scheme having a digital system at each terminal of the transmission line to be protected. Field tests for this system were completed in 1978 and the results were published in 1979 [37]. Minicomputer-based relay design activities were initiated at the University of New South Wales in early 1970s [46]. In 1976, this design was implemented by the Electricity Commission of New South Wales. The field tests started in 1978 and the results were published in 1980 [39]. Finally, a minicomputer-based protection system to be applied in low voltage substation (110 KV) was developed in Germany by the Siemens Corporation and the test results were reported in 1979 [40]. Obviously, all of the above approaches were of the centralized type since all of the functions were carried out by a minicomputer.

The final conclusions of the projects indicated, that, the idea of centralized protection system was feasible, but in order to achieve a flexible and sufficiently fast relaying function, a very fast and powerful computer system should be considered. This, in turn, implies a quite costly solution to the problem.

The above requirements for the cost-effective solution with superior performance characteristics were achieved with the introduction of microprocessor and the development of micro-computer-based relay. This led to the development of the second basic philosophy in designing digital relaying system, mainly the decentralized approach.

4.2.2 Decentralized Approach:

Microprocessors have been considered for relaying application since 1975 [43]. Several projects have been initiated for the development of transmission line protection system. Prototype system for microprocessor-based distance relay were developed and field tested by the Mitsubishi Electric Corporation and the Kansi Electric Power Company [38], as well as by the Tokyo Electric Company and Toshiba Corporation [42]. A software development for a transmission line protection was reported by the Saskatchewar Power Corporation, Canada [45].

All of the above implementation were based on the concept of decentralized applications. This means that the microprocessor based system were intended to perform only one protection function. The system performed satisfactorily compared to the conventional relays. The reported system were shown to be attractive, both cost wise as well as performance wise, when compared to the conventional system. However, most of the reports related to the microcomputer - based relays were published during the period 1977-1979 and there are very few papers published on their actual field testing.

4.2.3 Integrated Approach:

In this case, the protection system functions are distributed to a number of microprocessors which are then connected in an integrated manner. There are two basic types of integrated system.

a) Integrated protection systems

b) Integrated control and protection systems.

It should be noted that only one integrated system has been implemented [44] and tested by the Mitsubishi Electric Corporation and Kansai Electric Power Company of Japan. This is of control and protection type. This system was of a very limited scale in terms of the functions that were implemented.

The integrated systems are capable of performing the relaying functions in parallel. Each dedicated microprocessor exhibit performance characteristics which are similar to that of decentralized approach. At the same time, the system integration concept, provides the additional benefits of exclusive data acquisition and monitoring of the overall protective functions. This approach requires only a moderate system price increase when compared with the decentralized approach because of the communication subsystem. The benefits of integrated approach are numerous and include most of the benefits provided by the centralized and decentralized approaches. Some additional performance improvement is expected since the control and protection are combined and can be maintained and operated through a sophisticated man-machine interface. However, the integrated system are still in the proposal phase (state).

In the present work, the decentralized approach is used for the software/hardware system developments for the proposed relaying schemes for the protection of transmission line.

4.3 BLOCK SCHEMATIC DIAGRAM OF THE PROPOSED MICROPROCESSOR-BASED RELAYING SCHEME

A simplified hardware configuration of the proposed relay is shown in the Figure 4.1 as applied for the protection of EHV/UHV transmission line.

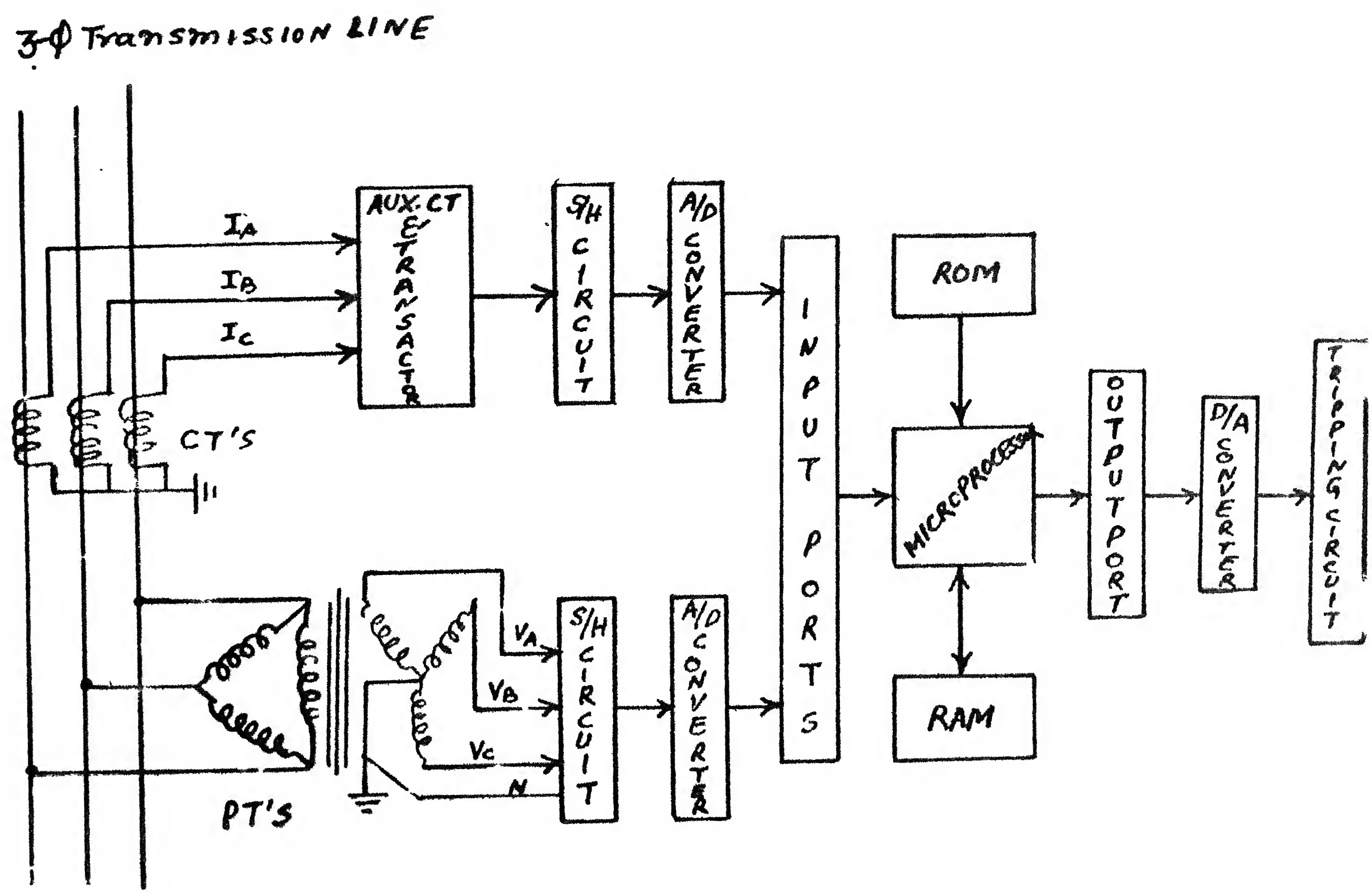


FIG 4.1: BLOCK SCHEMATIC OF THE PROPOSED RELAYING SCHEME

Data acquisition is done by sampling simultaneously the bus voltages and line currents by sample and hold circuits. These signals are converted into the digital form using Analog to digital converters and transmitted to the input ports of the microprocessor. Sampling interval is set by an external oscillator and to maintain the synchronization with the supply frequency phase locked loop (PLL) is used. The advantage of using PLL is that the sampling instant will be exactly same as that of previous cycle. The central processing unit is a microprocessor 8085 AH with a 8 bit word size. The basic cycle time is 200 nsec if crystal oscillator is of 10 MHz or 320 nsec if the crystal oscillator used is 6.144 MHz.

4.4 HARDWARE REALISATION

The relay which has been developed whose schematic diagram is given in Fig. 4.1, is sub-divided into four main sections.

a) Data acquisition system

b) Microcomputer

c) Secondary interface

d) Power supply

4.4.1 Data Acquisition System (DAS):

Data acquisition primarily includes circuits of

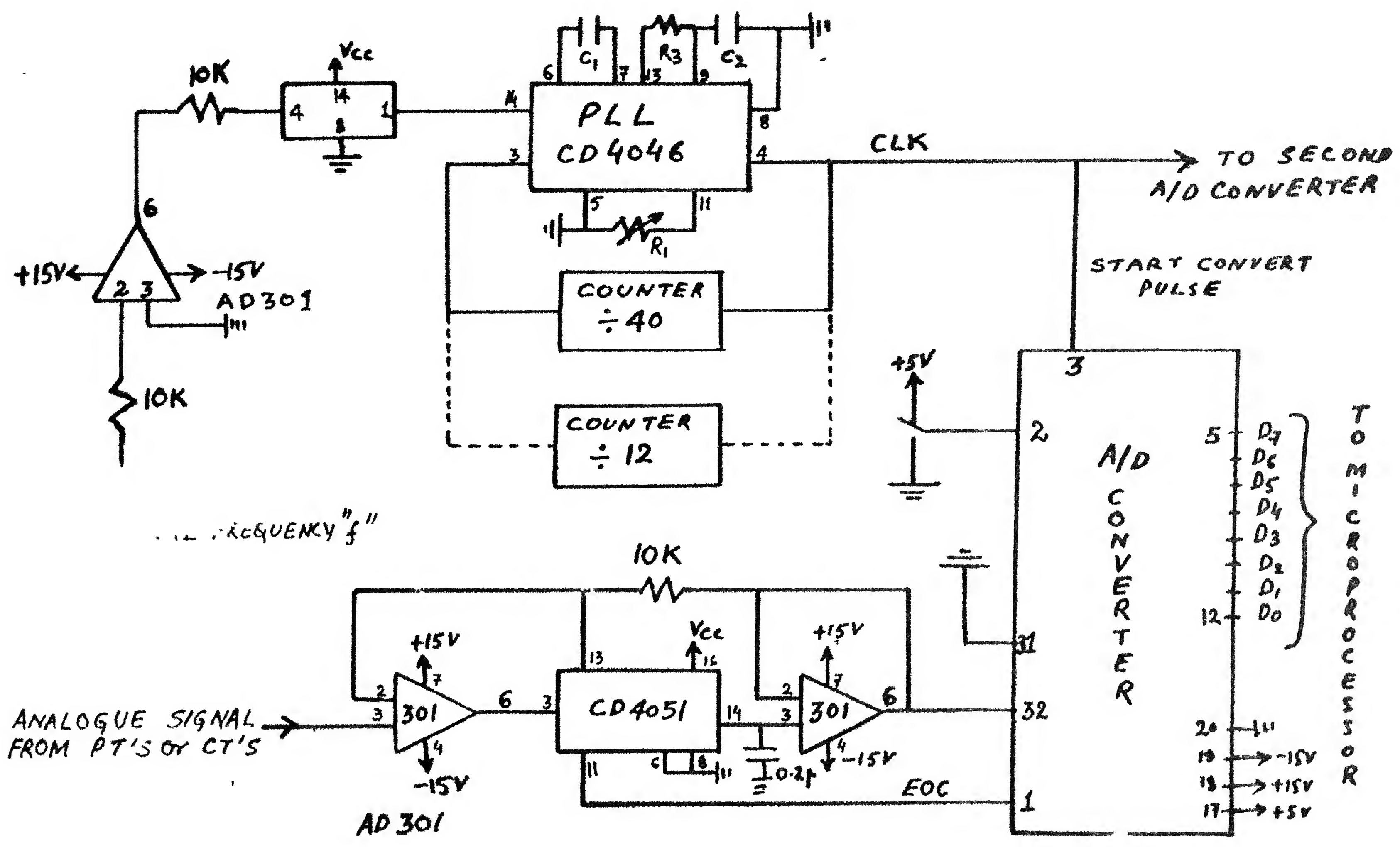


FIG 4.2: BLOCK SCHEMATIC OF DATA AQUISITION SYSTEM

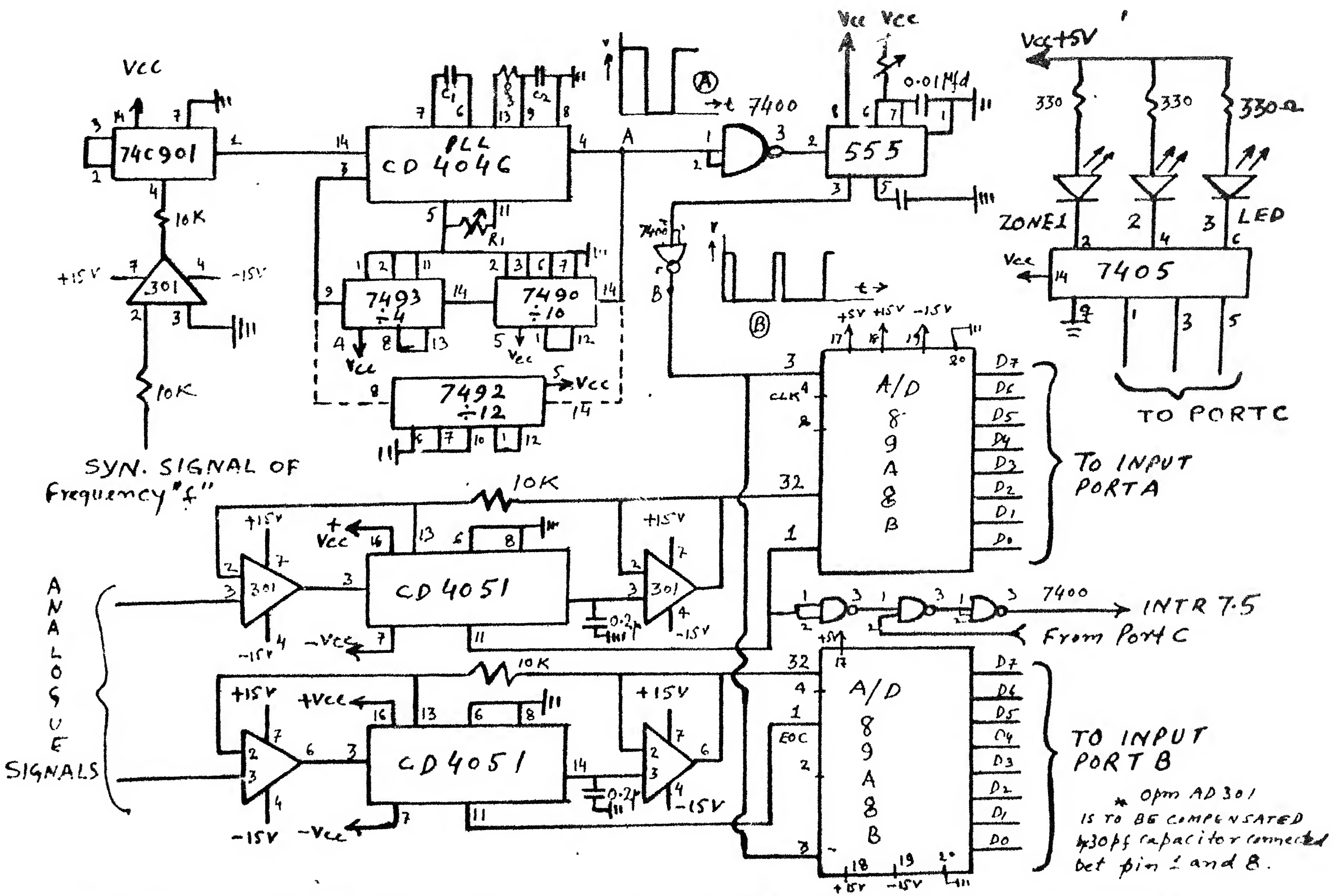


FIG 4.3: CONNECTION DIAGRAM OF DATA AQUISITION SYSTEM

synchronization, Sample/Hold and Analogue to digital converter. The block schematic and connection diagram of data acquisition system is given in Fig. 4.2 and Fig. 4.3 respectively.

The samples are taken at an interval of 0.5 ms i.e. 40 samples/cycle. To achieve this, 2 KHz external oscillator is required. Clock of 2 KHz has been generated using PLL 4046, this clock will always be in synchronism with the supply frequency. The synchronising supply signal is fed to the input of phase lock loop (PLL) after making the output of op-amp. TTL compatible using inverter 74C901. A division by 10 counter and a division by 4 counter are provided in the feedback path of the PLL. These counters serve the purpose of providing a frequency clock ($f_{ck} = 40 \times f$) at the terminals of the voltage controlled oscillator. To achieve a frequency of 600 cycle (12 samples/cycle) as required in the proposed scheme II, a counter divide by 12 is used.

The start convert pulse thus generated using PLL is given to ADC. The positive transition of start convert pulse triggers the ADC to start converting the previous sampled value into equivalent digital form. At the same time, end of conversion (EOC) status is made high putting the sampling circuit in hold mode (i.e. output of SHC is held constant in this period). After completion of the conversion, EOC is made low thereby putting the SHC in sampling mode (i.e. output

of sample and hold circuit changes during this period) and during the same time, digital data can be latched to processor through 8255. Again when the start convert pulse comes, same process is repeated.

4.4.2 Microprocessor Based System:

The circuit diagram of microprocessor (8085A) based system is given in Fig. 4.4. The microprocessor based system consists of microprocessor (8085A) and its associated IC's and the memories. On board, memory consists of EPROM (2716) and RAM (2114), 8255A provides I/O ports, three 16 bit programmable timers are provided using the 8253. The address map is as follows,

RAM	:	(2114x2)	:	1 K bytes
EPROM	:	2716	:	2 K bytes
I/O Ports	:	8255A		
TIMER	:	8253		

The full size double sided PCB has been developed. Sockets have been used for all IC's to avoid trouble later while checking. After inserting the sockets, the jumpers have been wired with the hook up wires. The power supply terminals of the IC's is connected to the +5V and ground points. A 0.01 µfd ceramic capacitor is connected between the supply terminals of the ICs. The

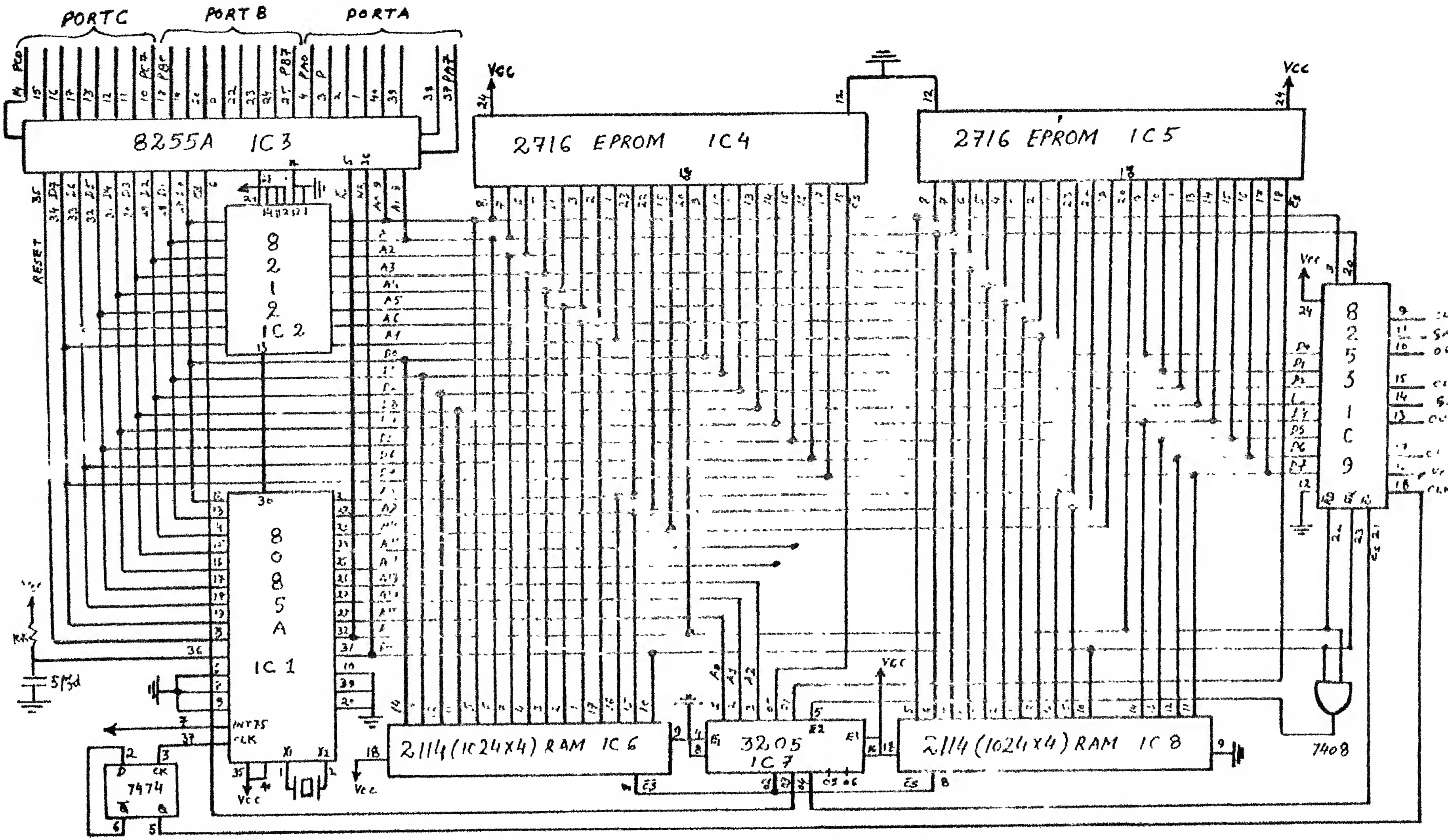


FIG 4.4 CONNECTION DIAGRAM OF MICRO-COMPUTER

6.144 MHz crystal oscillator is soldered between pin 1 and 2 of the microprocessor IC 8085A.

4.4.2.1 Circuit Description:

The 8085A IC is the heart of the circuit. It needs only a single +5V supply for its working. It has built-in timing oscillator and works by connecting a crystal between terminals 1 and 2. The frequency upto which it can be worked is 10 MHz, but in the circuit 6.144 MHz crystal is used. The cycle time is approximately 320 nsecs. The 40 pins of the IC 8085A are for Address lines, Data lines, Serial input and output, interrupt pins, Hold and Hold acknowledge, Resetting input and output as well as status signal for accessing the memory ICs and input/output ports.

The lines AD_0 to AD_7 carry both address and data information together, on a time sharing basis. The moments during which address information is present on the line is synchronously given by the pulse coming from pin 30 - the 'Address Latch Enable' pin (shown as ALE in circuit diagram Fig. 4.4). So, by catching this information at this instant on an 8-bit latch consisting of 8-D flip-flop, the address information is continuously available on the eight output of flip-flops. The 8212 IC is used for this purpose. The input to this, are the lines AD_0 to AD_7. The latched address information A_0 to A_7 comes out as eight lines from

8212. The AD_0 to AD_7 are now useful as Data lines D_0 to D_7 which go to the Data bus.

The address lines A_8 to A_{15} are coming continuously from the pins 21, 22, 23, 24, 25, 26, 27 and 28. In this circuit, all the lines are being used i.e. all 64 K memory is being used, but at present only 2K EPROM and 1K RAM is used. The circuit works in Memory mapped mode.

The control output pins of 8085 are I/O $\overline{M}$ (pin 34), $\overline{RD}$ (pin 32), $\overline{WR}$ (pin 31), S_0 (pin 29) and S_1 (pin 23). The control output pin I/O $\overline{M}$, S_0 and S_1 are not used in the circuit. The $\overline{RD}$ and $\overline{WR}$ signals are low while some data is being read or is written to either a port or a memory location.

The address decoding is done using address decoder IC 8205. The lines A_{13}, A_{14}, A_{15} are given to pin A_0, A_1 and A_2 of IC 8205 i.e. pin No. 1 to 3. To enable the decoder, the output after ANDING $\overline{RD}$ and $\overline{WR}$ using IC7400 (see Fig. 4.4) is given to enabling pin E_2 (pin 5) other enabling pin 4 is grounded and pin 6 (E_3) is connected to +5V V_{cc}. In this way, eight chip select is generated CS_{00} to CS_{07} (pin 15,14,...9 and 7). Thus, the addresses of EPROM, RAM, PPI and counter are as follows:

EPROM1 : CS00 : 0000H-IFFFH: 8K of memory can be address
: 0000H-07FFH: 2K of memory as EPROM1 is of 2K byte.

EPROM2	:	CS01	: 2000H - 3FFFH	: Available
			: 2000H - 27FFH	: Actual used
RAM	:	CS02	: 4000H - 5FFFH	: Available
			: 4000H - 43FFH	: Actual used
PPI 8255	:	CS03	: 6000H - 7FFH	: Available
			: 6000H - 6003	: Actual used
TIMER	:	CS04	: 8000H - 9FFH	: Available
			: 8000H - 8002	: Actual used

The other pins of the 8085 which are brought out via edge connector are:

INTR, TRAP, RST 5.5, RST 6.5, RST 7.5 (interrupt pins), clock and Reset out pin.

The five interrupt pins are to be normally kept low i.e. at '0' level and when any of four is made high i.e. 1 level, any programme that is running in the microprocessor is interrupted and execute the next instruction either from a fixed location in the memory (see Table 4.1) or executes a call instruction jammed onto its buses by some external device. The call instruction is executed if INTR lines goes high. When any of these five lines goes high, we say that an interrupt has occured. In the circuit given above in Fig. 4.4, only RST 7.5 is used and rest are grounded permanently.

Table 4.1

Interrupt Restart Location for 8085A

LINE	Location from which next instruction is picked up (HEX address)
TRAP	24
RST 5.5	2C (= 5.5 x 8)
RST 6.5	34 (= 6.5 x 8)
RST 7.5	3C (= 7.5 x 8)

The line RST 7.5 is made high periodically with reference to EOC status of A/D converter, only during the period the processor is engaged in calculation stage, to avoid the loss of any sample which are received by the ports from the data acquisition system.

The PPI (Programmable Peripheral Interface) IC 8255 is used in the circuit for Input/Output ports, which can be programmed in a variety of ways so as to suit a particular system configuration. Different operating mode of 8255 is Mode 0, Mode 1 and Mode 2. In the present system, PPI 8255 is used in Mode '0'. The 8255A PPI provides three 8 bit ports named A,B and C. The 24 lines provided, are divided into two groups: Group A and Group B. Lines in port A and four lines of port C, PC_4-PC_7 (called the upper portion

of port C), constitute Group A and those in port B and the lower four, PC_0 - PC_3, in port C constitute Group B. Each port can be programmed to be either . an input or an output port. Also, port A can be used as a bidirectional bus for input/output.

4.4.3 Power Supply System:

A +5V power supply is required for the microprocessor system and a total current of about 500 mA will be needed. Data acquisition system requires a +5V, -5V, +15V and -15V power supply and current requirement is approximately 400 mA.

4.5 LABORATORY TESTING

The software programmes developed in Chapter 3 for the proposed relaying schemes for transmission line protection are stored separately in different EPROM and each scheme is tested and relay has correctly tripped the line, the tripping of line is indicated by glowing of LED.

In steady state, the interrupt 7.5 is always kept low as processor is primarily engaged for receiving samples and comparison thus of, as for the programmes. On occurence of disturbance on the system, the processor inters into a fault routine, to avoid to lose any sample during the period of computation, the interrupt 7.5 is enabled and processor

is interrupted by the EOC status of A/D converter at a frequency approximately equal to the sampling frequency.

The dynamic testing of the relay to investigate the transient over-reach and accuracy/range curves, could not be performed because of limited facilities available.

The operating specification of the relay is as

Voltage signal (from PT's)	:	+5V to -5V AC maximum
Current signal (from CT's)	:	+5V to -5V AC maximum
Supply requirements	:	+5V DC +15V DC -15V DC - 5V DC

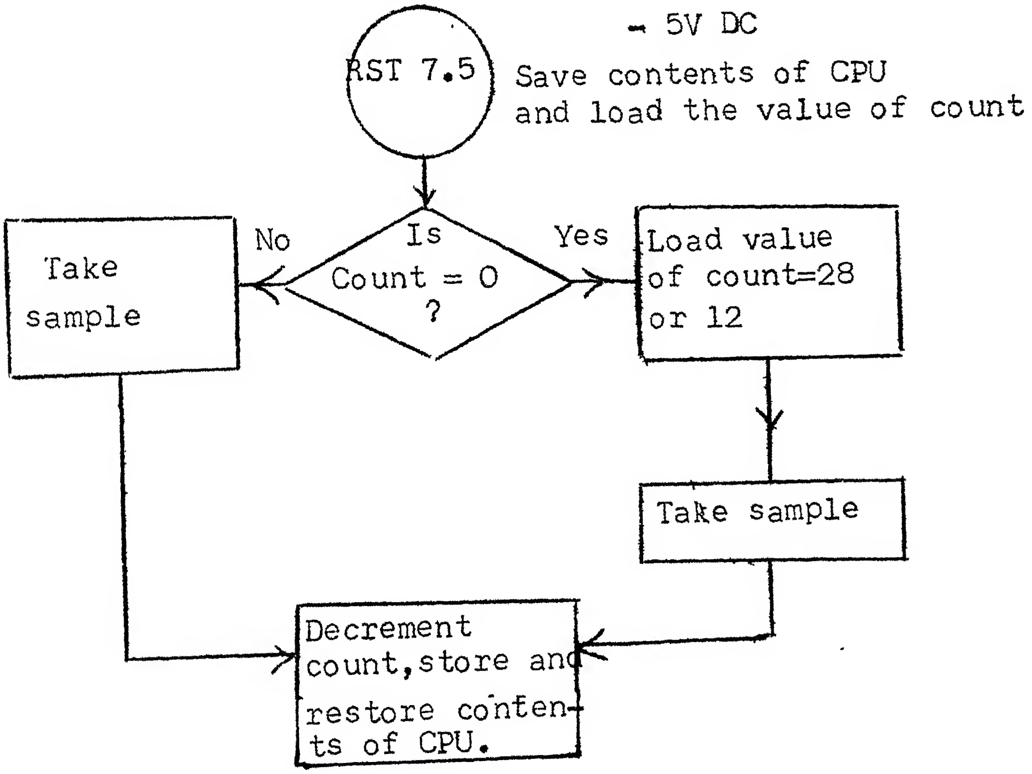


Fig. 4.5: Flow Chart 7.5 Interrupt Service Routine

CHAPTER 5

CONCLUSION

5.1 GENERAL

EHV and UHV transmission system needs a reliable, fast, efficient and low cost protection schemes, in order to transmit power reliably. Protection schemes using digital computers is a step ahead in this direction, as it is capable of realising complex threshold characteristics with lesser complexity and is of self checking nature. Accordingly, the primary objective of this thesis has been the design and development of microprocessor based protective relaying scheme. In the following sections, a brief account of the work carried out in this thesis, and also the scope for further work, are presented.

5.2 REVIEW OF THE WORK CARRIED OUT IN THIS THESIS

The protection schemes proposed in this thesis, are based upon the following two approaches:

a) Predictive calculation of peak fault current and voltage from a small number of sample values.

b) Fundamental component method taking samples for one-half power cycle.

In the proposed relaying scheme I, the software for realising three zone restricted Mho's relay characteristics has been developed which has been tested on a sample power system (see appendix D). The total operating time of relay from the instant the fault occurs is 4.94 ms for zone I,15.18ms for zone II and 25.44 ms for zone III. That is, the fault in zone I is cleared in less than a quarter cycle (5 ms).

In the proposed relaying scheme II, the software for realising three zone quadilateral characteristics has been developed and tested on a sample power system network (see Appendix D). The total operating time from the instant the fault occurs is 16.23 ms for zone I, 21.62 ms for zone II and 26.85 ms for zone III. That is, a fault in zone I is cleared in approximately one power cycle.

For the hardware realization of the above schemes, the relay based on microprocessor 8085 has been fabricated and tested. The relays comprises mainly, synchronising circuit; data acquisition system having sample/hold and analogue to digital converters; micro-computer using 8085A microprocessor. Provision exists for adding more memory and input/output ports if the situation demands. Visual display of the calculated fault impedance, distance to the fault point and type of fault can be obtained by interfacing TTY to the relay.

Any type of threshold characteristics such as that of plane impedance, direction relay, conical, hyperbola and over current relay can be obtained by developing the appropriate software.

5.3 SCOPE FOR FUTURE WORK

The proposed schemes, in single phase application, can be used for line to ground fault and in a three phase system, it can be used either for line to ground fault or phase to phase faults. However, the proposed relaying scheme can be extended for the discrimination of all the types of faults in three phase or multiphase system by using multiplexer and Direct Memory Access (DMA).

REFERENCES

1. K.L. Hicks and W.H. Butt, 'Feasibility and Economics of Ultra High Speed Fault Clearing', IEEE Trans., vol. PAS-99, Nov./Dec. 1980, pp. 2138-2145.

2. L.N. Crichton, 'The Distance Relay for Automatically Sectionalizing Electrical Networks', AIEE Trans. vol. XLII, 1923, pp. 527-537.

3. H.A. McLaughlin and E.O. Erickson, 'The Impedance Relay', AIEE Trans., vol. 47, 1928, pp. 776-782.

4. S.L. Goldsborough, 'A Distance Relay with Adjustable Phase-Angle Discrimination', AIEE Trans., vol. 63, 1944, pp. 835-838.

5. A.R. Van C. Warrington, 'Protective Relays - Their Theory and Practice', vol. I, John Wiley and Sons. Inc., New York,1962.

6. E.E. George, 'Operating Experience with Reactance-type Distance Relay', AIEE Trans., vol. 50, 1931, pp. 288-293.

7. A.R. Van C. Warrington, 'A High Speed Reactance Relay', Electrical Engineering, vol. 52, April 1933, pp. 248-252.

8. A.R. Van. C. Warrington, 'Protective Relaying for Long Transmission Lines', AIEE Trans., vol. 62, 1943, pp. 262-268.

9. R.E. Cordrey and A.R. Van C. Warrington, 'The Mho Carrier Relaying Scheme', AIEE Transactions, vol. 63, 1944, pp. 228-235.

10. R.M. Hutchinson, 'The Mho Distance Relay', AIEE Trans., vol. 65, June 1946, pp. 353-359.

11. J.E. Skuderna, 'A Mathematical Basis for Protective Relay with Conic Pick up Characteristics', AIEE Trans., vol. 81, Part III; 1962, pp. 81-88.

12. R. Wideroe, 'Thyratron Tubes in Relay Practice', AIEE Trans., vol. 53, Oct. 1934, pp. 1347-1353.

13. R.H. Mac Phevson, A.R. Van C. Warrington and A.J. Mc - Connell, 'Electronic Protective Relay', AIEE Trans., vol. 67, Part III, 1948, pp. 1702-1708.

14. F.R. Bergseth, 'An Electronic Distance Relay Using Phase-Discrimination Principle', AIEE Trans., vol. 73, Part IIIB, 1954, pp. 1276-1279.

15. C. Adamson and L.M. Wedepolel, 'Power System Protection with Particulars Reference to the Application of Junction Transistors to Distance Relay', Proc. IEE, vol. 103-A, Aug. 1956, pp. 379-388.

16. M. Ramamoorty and N.S. Wani, 'Static Distance Relay with Quadrilateral Characteristic', Presented at the IEEE Summer Power Meeting, 1970, Paper No. 70C571.

17. K. Parthasarthy et.al., 'An Adaptive Distance Relay for Protection of Transmission Lines', Conference paper, vol. 1, Conference on Power System Protection,Madras (India), April 16-19,1980, Paper No. A5.

18. M. Ramamoorty et.al., 'Static Distance Relay with Conic Characteristics', Conference paper, vol. I, Conference on Power System Protection, Madras, April 16-19,1980, Paper No. A-7.

19. G.D. Rockfeller, 'Fault Protection with a Digital Computer', IEEE Trans. vol. PAS-88, April 1969, pp. 438-464.

20. B.J. Mann and I.F. Morrison, 'Digital Calculation of Impedance for Transmission line with a Digital Computer', IEEE Trans. vol. PAS-90, March/April,1971, pp. 270-279.

21. A.K. Ghai, H.K. Verma, P. Mukhopadhyay, 'A Novel Directional over Current Relay Applying Microprocessor', Conference on Power System Protection, vol. 3, April 1980, Paper No. D-5.

22. G. Thirupathaiah, A. Varshney, L.P. Singh, 'On Line Digital Protection using Micro-computer', National Conference on Large Scale Power System, June 1982.

23. Y. Akimoto, M. Yamaura and T. Matsuhima, 'Digital Current Differential Carrier Relaying System for EHV Transmission Line', IFAC Control Science and Technology, Kyota Japan 1981, pp. 3291-3293.

24. Yoshiteru Miki et.al., 'Study of High Speed Distance Relay using Microprocessor', Trans. IEEE, PAS, vol. 96, No. 2, March-April 1977, pp. 602-613.

25. A.D. McInnes and I.F. Morrison, 'Real Time Calculation of Resistance and Reactance for Transmission Line Protection by Digital Computer', Trans., Inst. Eng., Australia, EE-7 (1971), pp. 16-23.

26. A.M. Ranjbar and B.M. Corey, 'Improved Method for the protection of High Voltage Transmission Line', Trans. IEEE, PAS-94, No. 2, March-April 1975, pp. 544-550.

27. G.S. Hope and V.S. Umamaheswaran, 'Sampling for Computer Protection of Transmission Lines', IEEE Trans., PAS-93, 1974, pp. 1522-1534.

28. M. Ramamoorty, 'A Note on Impedance Measurement using Digital Computer', IEE-IERE Proc. (India), 9(6), 1971, pp. 243-247.

29. J.G. Gilbert et.al., 'The Development and Selection of Algorithm for Relaying of Transmission Lines by Digital Computers,' in B.D. Russell and M.E. Council (eds), Power System Control and Protection, Academic Press, New York,1978, pp. 83-127.

30. A.G. Phadke, T. Hilbka and M. Ibrahim, 'A Digital Computer System for EHV Substation: Analysis and Field Test', IEEE Trans., PAS-95 (1976), pp. 291-301.

31. J.G. Bilbert et.al., 'High Speed Transmission Line Fault Impedance Calculation using a Dedicated Minicomputer' IEEE Trans., PAS-94, 1975, pp. 872-883.

32. J. Makino and M. Yoshiteru, 'Study of Operating Principles and Digital Filters for Protective Relays with Digital Computer', IEEE, PES Winter Meeting, IEEE Publn. No. 75CH 0990-2 PWR January 1975, Paper No. C75 197-9.

33. R.G. Lucketl, P.J. Munday and B.E. Murray, 'A Substation based Computer for Control and Protection, Modern Development in Protection', IEE London, 1975, Publn. No. 125, pp. 252-260.

34. A. Wisznicwski, 'How to Reduced Errors of Distance Fault Locating Algorithm', IEEE, Trans., PAS, vol. PAS-100, No. 12, Dec. 1981.

35. G.B. Gilcrest, G.D. Rockfeller and E.A. Udren, 'High Speed Distance Relaying using a Digital Computer', Part I - System Description, IEEE Trans., PAS-91, (1972) pp. 1235-1243.

36. E.A. Udren,'Prodar to Computer Relaying System - Field Experience and Staged Fault Tests', The second Annual Western Protective Relaying Conference, Preprints of Papers, Engineering Extension Service Washington State Univ. Oct. 1975.

37. M.M. Chen et.al., 'Field Experience with a Digital System for Transmission Line Protection', IEEE Trans., PAS-98, (1979), pp. 1796-1805.

38. K. Suzuki et.al., 'Results of Field Experiments of Digital Relays Utilizing Mini-computer and 1977 Microproccssor, IFAC Symposium on Automatic Control and Protection of Electric Power System, Feb. 1977, Institution of Engineers, Australia,1977, Publication No. 77/1 , pp. 312-316.

39. G. Varga et.al., 'Line Protection by Digital Computer in New South Wales,' Proceeding of IEE Conference on Developments in Power System Protection, Institution of Electric Engineers London, 1980, Publn. No. 185, pp. 117-122.

40. H. Strecken et.al., 'Network Protection with a Process Computer', Proceeding of the CIRED Meeting, Belgium, 1979, Paper No. 26.

41. K.V. Desikachar and L.P. Singh, 'Fault Analysis of Multimode Power System for Designing UHS Protective Relays along with Proposed Relaying Scheme'. Electrin Power System Research, 6(1983), pp. 13-25.

42. K. Suzuki et.al., 'A New Type Microprocessor Based Directional Distance Relay - Its Design and Field Experience', IEEE PES Summer Meeting July,1979, Paper No. A79418-J.

43. D.I. Rummer and M. Kezunovic, 'A Survey and Classification of Digital Computer Relaying Literature', IEEE, PES Summer Meeting, July 1979, Paper No. A79417-7.

44. K. Tanaka et.al., 'Application of Microprocessors to the Control and Protection System at Substation', IEEE Trans., PAS-99 (1980) pp. 344-351.

45. P.W. Davall and G. Au Yeung, 'A Software Design for a Computer based Impedance Relay for Transmission Line Protection', IEEE Trans., PAS-99 (1980), pp. 234-245.

46. B.J. Mann and I.F. Morrison, 'Relaying a Three Phase Transmission Line with Digital Computer', IEEE Trans., PAS-90 (1971), pp. 742-750.

47. A. Wright, 'Current Transformers: Their Transient and Steady State Performance', London: Chapman and Hall 1968.

48. A. Ralston, 'A First Course in Numerical Analysis', New York: McGraw-Hill 1965.

49. L. Fox, 'Numerical Solution of Ordinary and Partial Differential Equation' London: Pergaman, Reading Mass: Addison: Pergaman.

50. E. Isaacson and H.B. Keller, 'Analysis of Numerical Methods', New York: Wiley, 1966.

APPENDIX A

NUMERICAL INTEGRATION

The general problem of numerical integration may be stated as follows. Given a set of data points $(x_o y_o)$, $(x_1 y_1), \ldots (x_n y_n)$ of a function $y = f(x)$ where $f(x)$ is not known explicitly, it is required to compute the values of definite integral,

$$I = \int_a^b y \, dx \qquad \text{(A.1)}$$

Let the interval [a,b] be sub-divided into N equal subinterval, such that, $a = x_o < x_1 < x_2 < \ldots < x_N = b$ clearly $x_n = x_o + Nh$ where h is the step size (i.e. length of interval). Hence the integration becomes

$$I = \int_{x_o}^{x_N} ydx \qquad \text{(A.2)}$$

Consider the figure A.1 . Let the samples are taken at a uniform interval. If the interval is small, then the area enclosed by two samples is approximately of

quadilateral form. Then the total area enclosed by the curve over a definite period x_o, x_1 is given by,

$$I_1 = \int_{x_o}^{x_1} ydx = h\,[y_o + y_1] \qquad (A.3)$$

Generalising it for the interval [a,b], we get,

$$I = \int_{x_o}^{x_1} ydx + \int_{x_1}^{x_2} ydx + \ldots \int_{x_{N-1}}^{x_n} ydx \qquad (A.4)$$

$$= \frac{h}{2}\,[y_o + 2(y_1 + y_2 + \ldots + y_{N-1}) + y_N\,]$$

which is known as Trapezoidal rule.

To evaluate V_d, V_q, I_d and I_q numerically, the above trapezoidal rule is applied. From equation(3.19)thus we get,

$$V_d = \frac{3\pi}{2T\omega} \int_{t_1}^{t_1+T\omega} V_{(t)} \cos \omega_2(t-t_1-\frac{T\omega}{2})dt \qquad (A.5)$$

Here $T\omega$ = time period = b-a = Nh

$$V_d = \frac{3\pi}{2xNh} \times \frac{h}{2}\,[V_{(t_1)}\cos \omega_2(t_1-t_1-\frac{T\omega}{2}) + 2V_{(t_2)} \cos \omega_2$$

$$(t_2-t_1-\frac{T\omega}{2}) + 2V_{(t_3)}\cos\omega_2(t_3-t_1-\frac{T\omega}{2}) + \ldots$$

$$+ 2V_{(tN)}\cos\omega_2(t_N-t_1-\frac{T\omega}{2}) + V(t_{N+1})\cos\omega_2(t_{N+1}-t_1-\frac{T\omega}{2})]$$

Since $T\omega = 2\pi/\omega_2$.

$$V_d = \frac{+3\pi}{4N}\,[V_{(t_1)}\cos(-\pi)+2V_{(t_2)}\cos\left(\frac{2\pi}{N}-\pi\right)+2V_{(t_3)}\cos\left(\frac{4\pi}{N}-\pi\right)+\ldots$$

$$+\ 2V_{(tN)}\cos\left(\frac{(N-1)\pi}{N}-\pi\right)+V_{(tN+1)}\cos\ (+\pi)] \qquad (A.6)$$

Similarly, for

$$V_q = \frac{-3\pi}{8N}\,[V_{(t_1)}\sin(-\pi)+2V_{(t_2)}\sin\left(\frac{2\pi}{N}-\pi\right)+2V_{(t_3)}\sin\left(\frac{4\pi}{N}-\pi\right)+\ \ldots$$

$$+2V_{(tN)}\sin\left(\frac{(n-1)2\pi}{N}-\pi\right)+V_{(tN+1)}\sin(\pi)] \qquad (A.7)$$

$$I_d = \frac{+3\pi}{4N}\,[I_{(t_1)}\cos(-\pi)+2I_{(t_2)}\cos\left(\frac{2\pi}{N}-\pi\right)+2I_{(t_3)}\cos\left(\frac{4\pi}{N}-\pi\right)+\ \ldots$$

$$+\ 2I_{(tN)}\cos\left(\frac{(n-1)2\pi}{N}-\pi\right)+I_{(tN+1)}\cos(\pi)] \qquad (A.8)$$

$$I_q = \frac{-3\pi}{8N}\,[I_{(t_1)}\sin(-\pi)+2I_{(t_2)}\sin\left(\frac{2\pi}{N}-\pi\right)+2I_{(t_3)}\sin\left(\frac{4\pi}{N}-\pi\right)+\ \ldots$$

$$+2I_{(tN)}\sin\left(\frac{(n-1)2\pi}{N}-\pi\right)+I_{(tN+1)}\sin(\pi)\ ] \qquad (A.9)$$

Introducing $\frac{3\pi}{4N}$ = A constant and after simplification, we get,

$$V_d = A[V_{(t_1)}\cos\pi-2V_{(t_2)}\cos\frac{2\pi}{N} - 2V_{(t_3)}\cos\frac{4\pi}{N} - \ldots$$

$$-2V_{(tN)}\cos\frac{(N-1)2\pi}{N} + V_{(tN+1)}\cos\pi] \qquad (A.10)$$

$$V_q = A[V_{(t_1)}\frac{\sin\pi}{2}+V_{(t_2)}\sin\frac{2\pi}{N} + V_{(t_3)}\sin\frac{4\pi}{N} + \ldots$$

$$+V_{(tN)}\ \sin\frac{(N-1)2\pi}{N} - V_{(tN+1)}\ \frac{\sin\pi}{2}\ ] \qquad (A.11)$$

$$I_d = A[I_{(t_1)}\cos\pi - 2I_{(t_2)}\cos\frac{2\pi}{N} - 2I_{(t_3)}\cos\frac{4\pi}{N} - \dots$$

$$- 2I_{tN} \cos\frac{(N-1)2\pi}{N} + I_{(tN+1)}\cos\pi] \qquad (A.12)$$

$$I_q = A[I_{t_1} \frac{\sin\pi}{2} + I_{(t_2)}\sin\frac{2\pi}{N} + I_{(t_3)} \sin\frac{4\pi}{N} + \dots$$

$$+ I_{(tN)}\sin\frac{(N-1)2\pi}{N} - I_{(tN+1)} \frac{\sin\pi}{2}] \qquad (A.13)$$

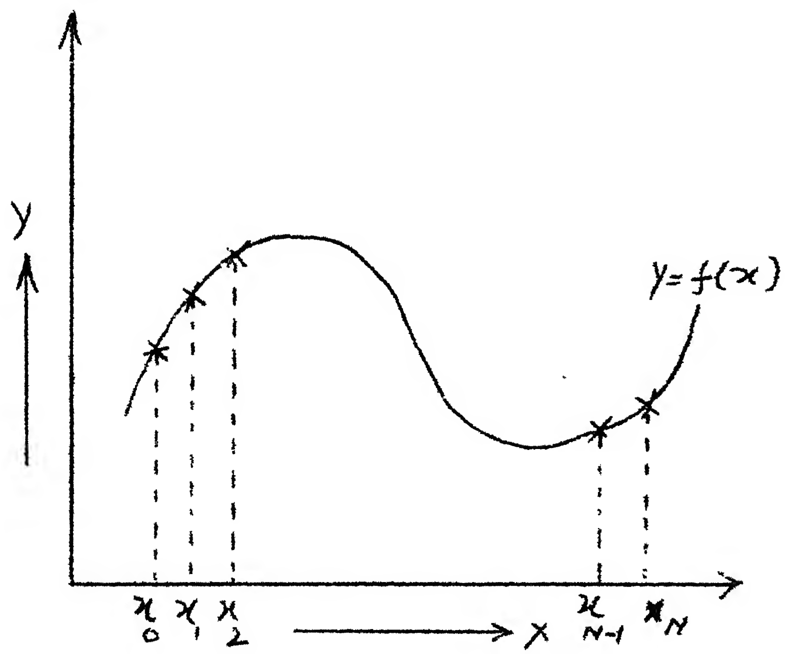


Fig. A-1

APPENDIX B

SELECTION OF SAMPLING RATE

Assume that the waveforms are sampled at an interval of Δt with actual sampling times being t_k , $t_{k+1}, \ldots$ and corresponding sampled value being $v_k, v_{k+1}, \ldots$ Take t_o as being half way between t_k and t_{k+1}. Then we get,

$$v_o = \frac{1}{2}(v_k+v_{k+1}) \tag{B.1}$$

$$v'_o \simeq \frac{\Delta v}{\Delta t} = \frac{1}{\Delta t}(v_{k+1}-v_k) \tag{B.2}$$

Since from (3.4) we know that,

$$V_{pk}^2 = (v)^2 + (\frac{v'}{\omega})^2 \tag{B.3}$$

So, this yields an estimate V_o of V at time t_o as

$$V_o^{\ 2} = v_o^{\ 2} + (\frac{\Delta v}{\omega \Delta \tau}\Big|_{t=t_o})^2 \tag{B.4}$$

Put the value of v_o and $\Delta v/\Delta t$ from equations(B.1) and (B.2) into equation (B.4) we get,

$$V_o^{\ 2} = [\frac{1}{2}(v_k+v_{k+1})\Big|_{t=t_o}]^2 + [\frac{v_{k+1}-v_k}{\omega\Delta t}\Big|_{t=t_o}]^2$$

$$= \frac{V_{pk}^2}{4}[\sin\omega t_o - \frac{1}{2}\omega\Delta t + \sin(\omega t_o + \frac{1}{2}\omega\Delta t]^2 + \frac{V_{pk}^2}{(\omega\Delta t)^2}\times$$

$$[\sin(\omega t_o + \frac{1}{2}\omega\Delta t) - \sin(\omega t_o - \frac{1}{2}\omega\Delta t]^2$$

Expanding the above and neglecting the high order term for sake of simplicity we get,

$$V_o = V_{pk} \left[1 - \frac{\omega^2 (\Delta t)^2}{4} \sin^2 \omega t_o + \ldots \right] \qquad (B.5)$$

For $\Delta t = 0.5$ ms, the equation (B.5), gives a maximum error in V_o on 50 Hz system of 0.15%, numerical analysis list the several ways of calculating the derivative [48]-[50]. In general, these methods are series expression of forward, backward or central differences. The actual formula for numerical differentation can be obtained by differentiating the interpolating polynomial, i.e. interpolation formula. Isaacon and Keeler [90] have shown that interpolation error are least near the centre of interval of interpolation which is equivalent of using interpolating formula developed using central difference. But it is advantageous, for real time implementation, to use backward difference for calculating the derivative using existing samples. These consideration led to the tentative selection of a sampling interval of 0.5 ms i.e. 40 samples per cycle.

APPENDIX C

DIFFERENTIATION FORMULAS

Using the standard notation ∇ , δ and μ for the operation of backward differencing, central differencing and averaging respectively, the basic central difference expression for derivative [49] is

$$hy'_k = (\mu\ \delta - \frac{1}{6}\ \mu\ \delta^3 + \frac{1}{30}\mu\ \delta^3 - \ldots)y_k) \qquad (C.1)$$

where $h = \Delta t$ and y stands for v and i respectively.

Using the first term only of the above result (eqn.C.1) we get,

$$hy'_k = \frac{1}{2}(y_{k+1} - y_{k-1}) \qquad (C.2)$$

And using also the second term of above result (eqn. C-1) we get,

$$hy'_k = -\frac{1}{12}(y_{k+2} + \frac{2}{3}y_{k-1} - \frac{2}{3}y_{k-1} + \frac{1}{12}y_{k-2}) \qquad (C.3)$$

the backward differences expression for derivative [49] is,

$$hy'_k = (\nabla - \frac{1}{2}\nabla^2 - \ldots)y_k \ \ldots \qquad (C.4)$$

Using the first term only of result (eqn. C.4) we get,

$$hy'_k = y_k - y_{k-1} \qquad (C.5)$$

And using also the second term of the result (eqn. C.4) we get,

$$hy'_k = \frac{1}{2}(y_k - y_{k-2}) \qquad (C.6)$$

From the above, it is clear, that, the expression at (C.2), (C.3) require sample value at times later than t_k, whereas expression (C.5) and (C.6) do not. Thus any of central difference and backward difference can be considered as possible ways of calculating the derivative.

APPENDIX D

TRANSMISSION LINE DATA [26]

Base	= 230 KV, 1000 MVA
Length of line	= 300 miles
Line Parameters:	
Positive sequence reactance	= $j0.123 \times 10^{-2}$ p.u.
Positive sequence resistance	= 0.223×10^{-3} p.u.
Zero sequence resistance	= 1.226×10^{-3} p.u.
Zero sequence reactance	= $j0.32 \times 10^{-3}$ p.u.
Positive sequence capacitive reactance	= $-j420$ p.u.
Zero sequence capacitive reactance	= $-j714$ p.u.
Source impedance Z_s	= $0.033+j0.315$

```
                      ;-----------------------------------------------------
                      ; REAL TIME MICROPROCESSOR BASED PROGRAMME FOR
                      ;THREE ZONE RESTRICTED MHO RELAY
                      ;-----------------------------------------------------
                      ;ASSIGNMENT MEMORY LOCATION FOR VARIBALES
4000                  DATUM EQU 4000H    ;SAMPLES OF VOLTAGE & CURRENT
0490                  COSTA EQU 0490H    ;COS LOOK UP TABLE
6000                  PORTV EQU 6000H   ;PORT 1 FOR VOLTAGE SAMPLES
6001                  PORTI EQU 6001H    ;PORT 2 FOR CURRENT SAMPLES
0410                  TANGT EQU 0410H      ;TAN LOOK UP TABLE
4056                  AMLA  EQU 4056H
4057                  VANGL EQU 4057H     ;STORING THE ANGLE OF VOLTAGE
4058                  IANGL EQU 4058H     ;STORING THE ANGLE OF CURRENT
4059                  FIRST EQU 4059H    ;STORING VALUE OF VPEAK SQUARE
405C                  SECND EQU 405CH   ;STORING VALUE OF IPEAK SQUARE
405E                  THIRD EQU 405EH   ;USED AS TEMPORARY STORAGE
4060                  FORTH EQU 4060H
4062                  FIFTH EQU 4062H
4064                  INTIC EQU 4064H
4065                  BASE EQU 4065H      ;USED AS TEMPORARY STORAGE
4066                  VBASE EQU 4066H
6002                  PORTC EQU 6002H     ;CONTROL PORT OF PPI
6003                  CWPPI EQU 6003H     ; CONTROL WORD OF PPI
4067                  VDERI EQU 4067H     ; STORING VOLTAGE DERIVATIVE
                              ; CURRENT,CURRENT DERIVATIVE
0000                  ORG 0000H
0000      31FF42      LXI SP,42FFH
                      ;+++++++++++++++++++++++++++++++++++++++++++++++++++++
                      ;INTIALISATION OF INPUTPORT/OUTPUTPORTS COUNTERS
                      ;+++++++++++++++++++++++++++++++++++++++++++++++++++++
0003      3E93         MVI A,93H     ; PORTA=INPUT=PORTB
                                ; PORTC LOWER=INPUT
                                ; PORTC UPPER=OUTPUT
0005      320360       STA CWPPT
0008      3E02         MVI A,02H
000A      325640       STA AMLA
000D      3E00         MVI A,00H
000F      320260       STA PORTC
0012      210040       LXI H,DATUM
0015      0E28         MVI C,28H
0017      3A0260      FLAKE: LDA PORTC
001A      1F           RAR
001B      DA2100       JC LAMB
001E      C31700       JMP FLAKE
0021      3A0060      LAMB : LDA PORTV
0024      CD6503       CALL DELHI
0027      77           MOV M,A
0028      23           INX H
0029      3A0160       LDA PORTI
002C      CD6503       CALL DELHI
002F      77           MOV M,A
0030      0D           DCR C
0031      CA8200       JZ FRESH
0034      C31700       JMP FLAKE
0037      00           NOP
0038      00           NOP
0039      00           NOP
003A      00           NOP
003B      00           NOP
003C      F5          RST75 :  PUSH PSW
003D      E5           PUSH H
003E      D5           PUSH D
003F      3A6440       LDA INTIC
0042      FE00         CPI 0H
0044      CA5C00       JZ HOLDG
0047      57           MOV D,A
0048      3E28         MVI A,28H
004A      92           SUB D
004B      210040       LXI H,DATUM
004E      5F           MOV E,A
004F      1600         MVI D,0H
0051      19           DAD D
0052      3A0060       LDA PORTV
0055      CD6503       CALL DELHI
```

```
0058    77          MOV M,A
0059    C36B00      JMP VERKT
005C    3E28        HOLDG: MVI A,28H
005E    325440      STA INTIC
0061    210040      LXI H,DATUM
0064    3A0060      LDA PORTV
0067    CD6503      CALL DELHI
006A    77          MOV M,A
006B    D1          VERKT: POP D
006C    E1          POP H
006D    F1          POP PSW
006E    C9          RET
006F    3A5440      ORGIN: LDA INTIC
0072    4F          MOV C,A
0073    3E28        MVI A,28H
0075    91          SUB C
0076    210040      LXI H,DATUM
0079    5F          MOV E,A
007A    1600        MVI D,0H
007C    19          DAD D
007D    1E00        MVI E,0H
007F    C3A100      JMP SAMPL
                    ;-----------------------------------------------
                    ;COLLECTION OF SAMPLES OF VOLTAGE AND CURRENT AND
                    ;CYCLE BY CYCLE COMPARISON OF VOLTAGE SAMPLES AND
                    ;REPLACING THE PREVIOUS BY LATEST SAMPLES OF VS C.
                    ;-----------------------------------------------
0082    1E00        FRESH: MVI E,00H
0084    0E28        MVI C,28H
0086    210040      LXI H,DATUM
0089    C3A100      JMP SAMPL
008C    23          INCR : INX H
008D    0D          DCR C
008E    CA8200      JZ FRESH
0091    C3A100      JMP SAMPL
0094    3E00        DECRE:  MVI A,0H
0096    BB          CMP E
0097    CA9B00      JZ GHOST
009A    1D          DCR E
009B    AF          GHOST:  XRA A
009C    23          INX H
009D    0D          DCR C
009E    CA8200      JZ FRESH
00A1    46          SAMPL:  MOV B,M
00A2    3A0260      BOTHM: LDA PORTC
00A5    1F          RAR
00A6    DAAC00      JC DOWER
00A9    C3A200      JMP BOTHM
00AC    3A0060      DOWER: LDA PORTV
00AF    CD6503      CALL DELHI
00B2    77          MOV M,A
00B3    23          INX H
00B4    3A0160      LDA PORTT
00B7    CD6503      CALL DELHI
00BA    77          MOV M,A
00BB    2B          DCX H
00BC    78          MOV A,B
00BD    55          MOV D,M
00BE    BA          CMP D
00BF    DAC500      JC LOCK
00C2    C3C800      JMP KEY
00C5    47          LOCK :  MOV B,A
00C6    7A          MOV A,D
00C7    50          MOV D,B
00C8    92          KEY  :  SUB D
00C9    1605        MVI D,05H
00CB    BA          CMP D
00CC    DAD200      JC MAXY
00CF    C3D700      JMP SOLO
00D2    AF          MAXY :  XRA A
00D3    23          INX H
00D4    C39400      JMP DECRE
00D7    1C          SOLO :  INR E
00D8    3E02        MVI A,02H
```

```
00DA   BB       CMP E
00DB   CAE200   JZ ZCAL
00DE   23       INX H
00DF   C38C00   JMP INCR
                ;--------------------------------------------------------
                ;CALCULATION OF IMPEDANCE
                ;--------------------------------------------------------
00E2   0D       ZCAL :  DCR C
00E3   79       MOV A,C
00E4   326140   STA INTIC
00E7   CD4403   CALL DERIV ;CALCULATE DERIVATIVE OF VOLTAGE
00EA   116740   LXI D,VDERT
00ED   3A6540   LDA BASE
00F0   326540   STA VBASE
00F3   EB       XCHG
00F4   78       MOV A,B
00F5   77       MOV M,A
00F6   23       INX H
00F7   79       MOV A,C
00F8   77       MOV M,A
00F9   EB       XCHG
00FA   23       INX H
00FB   23       INX H
00FC   23       INX H
00FD   CD4403   CALL DERIV  ;CALCULATE CURRENT DERIVATIVE
0100   216740   LXI H,VDERT
0103   23       INX H
0104   23       INX H
0105   78       MOV A,B
0106   77       MOV M,A
0107   23       INX H
0108   79       MOV A,C
0109   77       MOV M,A
                ;++++++++++++++++++++++++++++++++++++++++++++++++++++++
                ; CALCULATE  VALUE OF (VPEAK) AND (IPEAK) FROM
                ;LATEST VALUE OF SAMPLES AND DERIVATIVES
                ;++++++++++++++++++++++++++++++++++++++++++++++++++++++
010A   2B       DCX H
010B   2B       DCX H
010C   2B       DCX H
010D   AF       XRA A
010E   7E       LIME :MOV A,M
010F   47       MOV B,A
0110   E5       PUSH H
0111   CD7703   CALL MULTI
0114   225E40   SHLD THIRD
0117   E1       POP H
0118   23       INX H
0119   7E       MOV A,M
011A   0610     MVI B,10H
011C   E5       PUSH H
011D   CD7703   CALL MULTI
0120   4D       MOV C,L
0121   44       MOV B,H
0122   1600     MVI D,00H
0124   1E05     MVI E,05H
0126   7C       MOV A,H
0127   BB       CMP E
0128   DA3301   JC PHULN
012B   CDB703   CALL VISON ;REG B-C CONTAINS QUOTIENT
012E   79       MOV A,C
012F   41       MOV B,C
0130   C33901   JMP SUNDR
0133   43       PHULN: MOV B,E
0134   CD9503   CALL DIVIS
0137   7A       MOV A,D
0138   42       MOV B,D
0139   CD7703   SUNDR: CALL MULTI
013C   EB       XCHG
013D   2A5E40   LHLD THIRD
0140   19       DAD D
0141   3A5640   LDA ANLA
0144   3D       DCR A
0145   C24B01   JNZ TIMES
```

```
0148   C35C01       JMP FUNES
014B   325540      FINES: STA AMDA
014E   7D           MOV A,L
014F   44           MOV B,H
0150   215940       LXI H,FIRST
0153   77           MOV M,A
0154   23           INX H
0155   78           MOV A,B
0156   77           MOV M,A
0157   E1           POP H
0158   23           INX H
0159   C30E01       JMP DIME
015C   3C          FUNES: INR A
015D   3C           INR A
015E   325540       STA AMDA
0161   7D           MOV A,L
0162   44           MOV B,H
0163   215C40       LXI H,SECND
0166   77           MOV M,A
0167   23           INX H
0168   78           MOV A,B
0169   77           MOV M,A
016A   E1           POP H
016B   2B           DCX H
016C   2B           DCX H
016D   2B           DCX H
                   ;------------------------------------------------------
                   ; CALCULATE RAITO  .( R= /( / ) =32 /  OBTAINED AS
                   ;0.32 / *100=32 /  (              ) TO GET ANGLE
                   ;CALCULATE RATIO OF VOLTAGE /VOLTAGE DERIVATIVE/
                   ;AND FOR CURRENT DIVIDED BY CURRENT DERIVATIVE/
                   ;------------------------------------------------------
016E   7E          NATH :  MOV A,M  ;
016F   0620         MVI B,20H
0171   E5           PUSH H
0172   CD7703       CALL MULTI  ;
0175   4D           MOV C,L
0176   44           MOV B,H
0177   E1           POP H
0178   23           INX H
0179   5E           MOV E,M
017A   1600         MVI D,00H
017C   E5           PUSH H
017D   CD8703       CALL VISON    ;REG B-C CONTAINS QUOTIENT
0180   59           MOV E,C
0181   50           MOV D,B
0182   E1                POP H
0183   0E00         MVI C,00H
0185   7A           MOV A,D
0186   E607         ANI 00000111B
0188   1F           RAR
0189   DA9701       JC NAMAK
018C   1F           RAR
018D   DAA101       JC HARAM
0190   1F          KISAN :  RAR
0191   DAAB01       JC ARMAN
0194   C3AF01       JMP KUTAB
0197   0C          NAMAK :  INR C
0198   3F           CMC
0199   1F           RAR
019A   DAA101       JC HARAM
019D   3F           CMC
019E   C39001       JMP KISAN
01A1   0C          HARAM :  INR C
01A2   0C           INR C
01A3   3F           CMC
01A4   1F           RAR
01A5   DAAB01       JC ARMAN
01A8   C3AF01       JMP KUTAB
01AB   0C          ARMAN :  INR C
01AC   0C           INR C
01AD   0C           INR C
01AE   0C           INR C
01AF   3E00        KUTAB :  MVI A,00H
```

```
0181    B9              CMP C
01B2    CADC01          JZ KARZ
01B5    3E01            MVI A,01H
01B7    B9              CMP C
01B8    CAE501          JZ KARAM
01BB    3E02            MVI A,02H
01BD    B9              CMP C
01BE    CAF201          JZ GANDI
01C1    3E03            MVI A,03H
01C3    B9              CMP C
01C4    CA0002          JZ MANDI
01C7    3E04            MVI A,04H
01C9    B9              CMP C
01CA    CA0F02          JZ SUBZI
01CD    3E05            MVI A, 05H
01CF    B9              CMP C
01D0    CA1402          JZ JANAK
01D3    3E06            MVI A,06H
01D5    B9              CMP C
01D6    CA1902          JZ PURI
01D9    C31902          JMP PURI
01DC    AF             KARZ : XRA A
01DD    7B              MOV A,E
01DE    E6FC            ANI 11111100B
01E0    0F              RRC
01E1    0F              RRC
01E2    C31E02          JMP GUDDI
01E5    AF             KARAM: XRA A
01E6    7B              MOV A,E
01E7    E6F0            ANI 11110000B
01E9    0F              RRC
01EA    0F              RRC
01EB    0F              RRC
01EC    0F              RRC
01ED    C63F            ADI 03FH
01EF    C31E02          JMP GUDDI
01F2    AF             GANDI : XRA A
01F3    7B              MOV A,E
01F4    E6E0            ANI 11100000B
01F6    0F              RRC
01F7    0F              RRC
01F8    0F              RRC
01F9    0F              RRC
01FA    0F              RRC
01FB    C64E            ADI 04EH
01FD    C31E02          JMP GUDDI
0200    AF             MANDI: XRA A
0201    7B              MOV A,E
0202    E6C0            ANI 11000000B
0204    0F              RRC
0205    0F              RRC
0206    0F              RRC
0207    0F              RRC
0208    0F              RRC
0209    0F              RRC
020A    C655            ADI 55H
020C    C31E02          JMP GUDDI
020F    3E58           SUBZI: MVI A,58H
0211    C31E02          JMP GUDDI
0214    3E5B           JANAK : MVI A,05BH
0216    C31E02          JMP GUDDI
0219    3E5E           PURI: MVI A,05EH
021B    C31E02          JMP GUDDI
021E    5F             GUDDI: MOV E,A
021F    1600            MVI D,00H
0221    E5              PUSH H
0222    211004          LXI H,TANGT
0225    19              DAD D
0226    7E              MOV A,M
0227    47              MOV B,A
0228    E1              POP H
0229    3A5640          LDA AMDA
022C    3D              DCR A
022D    C23302          JNZ PATIL
```

```
0230    C34402    JMP SOHAN
0233    325540    PATIL:  STA AMGA
0236    3A6540    LDA VBASE
0239    FE00      CPI 00H
023B    CA4202    JZ PANAM
023E    90        SUB B
023F    C34302    JMP SOANG
0242    80        PANAM: ADD B
0243    325740    SOANG: STA VANGL
0246    23        INX H
0247    C36301    JMP MATH
024A    3A6540    SOHAN:  LDA BASE
024D    FE00      CPI 00H
024F    CA5502    JZ CANAL
0252    90        SUB B
0253    C35702    JMP RIVER
0256    80        CANAL: ADD B
0257    325840    RIVER: STA TANGL
                  ;------------------------------------------------
                  ; CALCULATE IMPEDANCE , COMPARE WITH  SET VALUE
                  ;------------------------------------------------
025A    2A5C40    LHLD SECND
025D    EB        XCHG
025E    2A5940    LHLD FIRST
0261    0600      MVI B,0H
0263    CDFC03    CALL LTQUD
                  ;REG B = QUOTIENT ,H-L= REMAINDER
                  ;REG D-E CONTAINS SECND(DIVISOR)
0266    AF        XRA A
0267    78        MOV A,B
0268    07        RLC
0269    07        RLC
026A    07        RLC
026B    80        ADD B
026C    80        ADD B
                  ;REG A CONTAINS 10*QUOTIENT
                  ;REGPAIR H-L CONTAINS REMAINDER
026D    4D        MOV C,L
026E    44        MOV B,H
026F    29        DAD H
0270    29        DAD H
0271    29        DAD H
0272    09        DAD B
0273    09        DAD B
0274    47        MOV B,A
                  ;  CHECK WHETHER  CONTENTS OF  REG  H-L
                  ;IS GREATER THAN CONTENTS OF REG PAIR D-E
                  ;CONTENTS OF H-L =10*REMAINDER
0275    7D        MOV A,L
0276    BB        CMP E
0277    DA8202    JC MSUB
027A    7C        MOV A,H
027B    BA        CMP D
027C    DA8C02    JC MONA
027F    C38902    JMP APPAR
0282    AF        MSUB :  XRA A
0283    7C        MOV A,H
0284    3D        DCR A
0285    BA        CMP D
0286    DA8C02    JC MONA
0289    CDFC03    APPAR: CALL LTQUD
                  ;------------------------------------------------
                  ; CALCULATE  ANGLE OF IMPEDANCE AND  CHECK WHETHER
                  ; IT LIES WITHIN 0+30 DEGRES
                  ;------------------------------------------------
028C    215740    MONA: LXI H, VANGL
028F    58        MOV E,B ;REG E CONTAINS VALUE OF IMPEDANCE
0290    7E        MOV A,M
0291    57        MOV D,A
0292    23        INX H
0293    4E        MOV C,M
0294    B9        CMP C
0295    DA9C02    JC POWER
0298    91        SUB C
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0299   C3A202    JMP IMPAN
029C   79       POWER:  MOV A,C
029D   92        SUB D
029E   47        MOV B,A
029F   3E34      MVI A,034H
02A1   90        SUB B
02A2   065A     IMPAN:  MVI B,054H
02A4   B8        CMP B
02A5   DAAB02    JC STORE
02A8   C35F03    JMP ORGIN
                 ; REG A CONTAINS ANGLE OF IMPEDANCE
                 ;REG E CONTAINS CALCULATED IMPEDANCE
02AB   57       STORE:  MOV D,A
02AC   0641      MVI B,41H
02AE   B8        CMP B
02AF   DAB502    JC SALT
02B2   90        SUB B
02B3   C3B802    JMP SUGAR
02B6   78       SALT :  MOV A,B
02B7   92        SUB D
02B8   C3B802    JMP SUGAR
02BB   FE00     SUGAR:  CPI 00H
02BD   CAFD02    JZ CAMPA
                 ; TO CALCULATE ZR**(COS**&1)>ZC**
02C0   219004   COALA:  LXI H,COSTA
02C3   42        MOV B,D
02C4   43        MOV C,E
02C5   1600      MVI D,0H
02C7   5F        MOV E,A
02C8   83        ADD E
02C9   5F        MOV E,A
02CA   19        DAD D
02CB   7E        MOV A,M
02CC   5F        MOV E,A
02CD   23        INX H
02CE   7E        MOV A,M
02CF   57        MOV D,A
02D0   EB        XCHG
02D1   226040    SHLD FORTH
02D4   29        DAD H
02D5   29        DAD H
02D6   225E40    SHLD THIRD   ;
02D9   AF        XRA A
02DA   79        MOV A,C
02DB   07        RLC
02DC   07        RLC
02DD   81        ADD C
02DE   06C8      MVI B,0C8H
02E0   CD7703    CALL MULTI
02E3   EB        XCHG
02E4   2A5E40    LHLD THIRD
02E7   7D        MOV A,L
02E8   BB        CMP E
02E9   DAF402    JC LIMCA
02EC   7C        MOV A,H
02ED   BA        CMP D
02EE   DA0503    JC ZONE2
02F1   C31E04    JMP TRIP1
02F4   7C       LIMCA:  MOV A,H
02F5   3D        DCR A
02F6   BA        CMP D
02F7   DA0503    JC ZONE2
02FA   C31E04    JMP TRIP1
02FD   7B       CAMPA:  MOV A,E
02FE   FE28      CPI 28H
0300   DA1E04    JC TRIP1
0303   C30503    JMP ZONE2
                 ;---------------------------------------------------------
                 ;TO CHECK FOR ZONE2 OPERATION
                 ;---------------------------------------------------------
                 ;REG PAIR H-L CONTAIN 4C05(A)
0306   29       ZONE2: DAD H
0307   226240    SHLD FIFTH
030A   D5        PUSH D
```

```
0308   EB       XCHG
030C   2A5D40   LHLD FORTH
030F   19       DAD D
0310   D1       POP D
                ;REG PAIR H-L CONTAIN BOOS(S)
0311   7D       MOV A,L
0312   BB       CMP E
0313   DA1E03   JC SCROL
0316   7C       MOV A,H
0317   BA       CMP D
0318   DA2703   JC ZONE3
031B   C32604   JMP TRIP2
031E   7C       SCROL: MOV A,H
031F   3D       DCR A
0320   BA       CMP D
0321   DA2703   JC ZONE3
0324   C32604   JMP TRIP2
                ;------------------------------------------------
                ; TO CHECK FOR ZONE3 OPERATION
                ;------------------------------------------------
0327   2A6240   ZONE3: LHLD FIFTH
032A   29       DAD H
032B   7D       MOV A,L
032C   BB       CMP E
032D   DA3803   JC SHIFT
0330   7C       MOV A,H
0331   BA       CMP D
0332   DA4103   JC PEPSI
0335   C32E04   JMP TRIP3
0338   7C       SHIFT: MOV A,H
0339   3D       DCR A
033A   BA       CMP D
033B   DA4103   JC PEPSI
033E   C32E04   JMP TRIP3
0341   C36F00   PEPSI: JMP ORGIN
                ;------------------------------------------------
                ;          SUBROUTINES
                ;------------------------------------------------
0344   46       DERTV : MOV B,M
0345   50       MOV D,B
0346   2B       DCX H
0347   2B       DCX H
0348   7E       MOV A,M
0349   B8       CMP B
034A   DA5803   JC RAJNI
034D   48       MOV C,B
034E   47       MOV B,A
034F   50       MOV D,B
0350   3E80          MVI A,080H
0352   325540   STA BASE
0355   C35E03   JMP RANY
0358   4F       RAJNI: MOV C,A
0359   3E00     MVI A,00H
035B   325540   STA BASE
035E   78       RANY : MOV A,B
035F   91       SUB C
0360   47       MOV B,A
0361   80       ADD B
                ; REG A CONTAINS DERIVATIVE
0362   4F       MOV C,A
0363   42       MOV B,D
0364   C9       RET
                ;++++++++++++++++++++++++++++++++++++++++++++++++
                ;TO CONVERT THE OFFSET BINARY NUMBER
                ;++++++++++++++++++++++++++++++++++++++++++++++++
0365   37       DELHI: STC
0366   3F       CMC
0367   17       RAL
0368   DA7303   JC TRECI
036B   1F       RAR
036C   F680     ORI 10000000B
036E   2F       CMA
036F   3C       INR A
0370   C37603        JMP KORAN
```

```
0373  1F      TRCC1: RAR
0374  E67F     ANI 01111111B
0376  C9      KORAR: RET
              ;++++++++++++++++++++++++++++++++++++++++++++++++++
              ; MULTIPLICATION SUBROUTINE
              ;MULTIPLIER IN REG A AND MULTIPLICANT IN REG B
              ;RESULT IN REG PAIR H AND L
              ;++++++++++++++++++++++++++++++++++++++++++++++
0377  210000  MULTI : LXI H,0000H
037A  1608     MVI D,08H
037C  48       MOV C,B
037D  44       MOV B,H
              ;MULTIPLIER IN REG A AND MULTIPLICANT IN B-
037E  0F      CASIO : RRC
037F  D28303   JNC SIGN
0382  09       DAD B
0383  15      SIGN : DCR D
0384  CA9403   JZ ASHTR
0387  5F       MOV E,A
0388  79       MOV A,C
0389  37       STC
038A  3F       CMC
038B  17       RAL
038C  4F       MOV C,A
038D  78       MOV A,B
038E  17       RAL
038F  47       MOV B,A
0390  7B       MOV A,E
0391  C37E03   JMP CASIO
0394  C9      ASHTR: RET
              ;++++++++++++++++++++++++++++++++++++++++++++++++++
              ; DIVISON SUBROUTINE REG D QUOTIENT REG B DIVISOR
              ;++++++++++++++++++++++++++++++++++++++++++++++++++
0395  78      DIVIS: MOV A,B
0396  1600     MVI D,00H
0398  1E00     MVI E,00H
039A  7B      DUSTL : MOV A,E
039B  FE08     CPI 08H
039D  CAAF03   JZ BLADE
03A0  29       DAD H
03A1  1C       INR E
03A2  7A       MOV A,D
03A3  07       RLC
03A4  57       MOV D,A
03A5  7C       MOV A,H
03A6  90       SUB B
03A7  DAAC03   JC SOAP
03AA  14       INR D
03AB  67       MOV H,A
03AC  C39A03  SOAP : JMP DUSTL
03AF  7C      BLADE : MOV A,H
03B0  07       RLC
03B1  B8       CMP B
03B2  DAB603   JC WATER
03B5  14       INR D
03B6  C9      WATER : RET
              ;==================================================
              ;16 BITS DIVISON SUBROUTINE REG B-C PAIR INTIALLY
              ;CONTAINS DIVEDEND REG  D-E= DIVISOR IN END
              ;REG B-C=QUOTIENT, REG H-L CONTAINS REMAINDER
              ;==================================================
03B7  210000  VISON: LXI H,0000H
03BA  D5       PUSH D
03BB  7A       MOV A,D
03BC  2F       CMA
03BD  57       MOV D,A
03BE  7B       MOV A,E
03BF  2F       CMA
03C0  5F       MOV E,A
03C1  13       INX D
03C2  3E11     MVI A,17D
03C4  E5      MINTD: PUSH H
03C5  19       DAD D
03C6  D2CA03   JNC CHINT
```

```
03C9   E3              XTHL
03CA   E1           CHINI: POP H
03CB   F5              PUSH PSW
03CC   79              MOV A,C
03CD   17              RAL
03CE   4F              MOV C,A
03CF   78              MOV A,B
03D0   17              RAL
03D1   47              MOV B,A
03D2   7D              MOV A,L
03D3   17              RAL
03D4   6F              MOV L,A
03D5   7C              MOV A,H
03D6   17              RAL
03D7   67              MOV H,A
03D8   F1              POP PSW
03D9   3D              DCR A
03DA   C2C403          JNZ MINTO
                    ;SHIFT REMAINDER RIGHT & RETURN IN H-L
03DD   B7              ORA A
03DE   7C              MOV A,H
03DF   1F              RAR
03E0   67              MOV H,A
03E1   7D              MOV A,L
03E2   1F              RAR
03E3   6F              MOV L,A
03E4   D1              POP D
03E5   29              DAD H
03E6   7D              MOV A,L
03E7   BB              CMP E
03E8   DAF303          JC LSUB
03EB   7C              MOV A,H
03EC   BA              CMP D
03ED   DAFB03          JC IONA
03F0   C3FA03          JMP SIPPU
03F3   AF           LSUB : XRA A
03F4   7C              MOV A,H
03F5   3D              DCR A
03F6   BA              CMP D
03F7   DAFB03          JC IONA
03FA   03           SIPPU: INX B
03FB   C9           IONA : RET   ;REG B-C=QUOTIENT
                    ;++++++++++++++++++++++++++++++++++++++++++++
                    ;TO FIND IMPEDANCE FROM VPEAK AND IPEAK
                    ;+++++++++++++++++++++++++++++++++++++++++++++++++++
03FC   AF           LIQUD: XRA A
03FD   7D              MOV A,L
03FE   9B              SBB E
03FF   6F              MOV L,A
0400   7C              MOV A,H
0401   9A              SBB D
0402   67              MOV H,A
0403   04              INR B
0404   AF              XRA A
0405   7D              MOV A,L
0406   BB              CMP E
0407   DA1204          JC DONE
040A   7C              MOV A,H
040B   BA              CMP D
040C   DA1C04          JC ERASE
040F   C3FC03          JMP LIQUD
0412   AF           DONE : XRA A
0413   7C              MOV A,H
0414   3D              DCR A
0415   BA              CMP D
0416   DA1C04          JC ERASE
0419   C3FC03          JMP LIQUD
041C   AF           ERASE : XRA A
041D   C9              RET   ;AS RESULT REG H-L CONTAINS REMAINDER
                    ;++++++++++++++++++++++++++++++++++++++++++++++++++++
                    ;          TRIP SIGNAL
                    ;++++++++++++++++++++++++++++++++++++++++++++++++++++
041E   3E80         TRIP1: MVI A,80H
0420   320260          STA PORTC
```

```
0423    C31E04           JMP TRIP1
0425    3E20        TRIP2: MVI A,20H
0428    320260           STA PORTC
042B    C32504           JMP TRIP2
042E    3E40        TRIP3: MVI A,40H
0430    320260           STA PORTC
0433    C32E04           JMP TRIP3
0436    76                  HLT
0410                    ORG TANGT
0410    02050709 DB 2H,5H,7H,9H,0BH,0EH,10H,12H,14H,16H,18H
0414    0B0E1012
0418    141618
041B    1A1C1D1F DB 1AH,1CH,1DH,1FH,21H,22H,24H,25H,27H
041F    21222425
0423    27
0424    28292B2C DB 28H,29H,2BH,2CH,2DH,2EH,2FH,30H,31H,32H
0428    2D2E2F30
042C    3132
042E    33343536 DB 33H,34H,35H,36H,36H,37H,38H,39H,39H,3AH
0432    36373839
0436    393A
0438    3B3B3C3C DB 3BH,3BH,3CH,3CH,3DH,3EH,3EH,3EH,3FH,3FH
043C    3D3E3E3E
0440    3F3F
0442    40404141 DB 40H,40H,41H,41H,41H,42H,42H,43H,43H,43H
0446    41424243
044A    4343
044C    44444445 DB 44H,44H,44H,45H,46H,47H,48H,49H,4AH,4BH
0450    46474849
0454    4A4B
0456    4B4C4C4C DB 4BH,4CH,4CH,4CH,4DH,4EH,4EH,4EH,4FH,50H
045A    4D4E4E4E
045E    4F50
0460    50515152 DB 50H,51H,51H,52H,52H,52H,53H,54H,55H,55H
0464    52525354
0468    5555
046A    56575757 DB 56H,57H,57H,57H,58H,58H,58H
046E    585858
0490                    ORG COSTA
0490    10270C27 DB 10H,27H,0CH,27H,01H,27H,0DFH,26H,0C4H,27H
0494    01270F26
0498    C427
049A    A2267B26 DB 0A2H,26H,7BH,26H,4EH,26H,1BH,26H,0E2H,25H
049E    4E261B26
04A2    E225
04A4    A3255F25 DB 0A3H,25H,5FH,25H,16H,25H,0C6H,24H,72H,24H
04A8    1625C624
04AC    7224
04AE    1824B923 DB 18H,24H,0B9H,23H,55H,23H,0ECH,22H,7EH,22H
04B2    5523EC22
04B6    7E22
04B8    08229421 DB 08H,22H,94H,21H,19H,21H,99H,20H,16H,20H
04BC    19219920
04C0    1620
04C2    8E1F031F DB 8EH,1FH,03H,1FH,74H,1EH,0E1H,1DH,48H,1DH
04C6    741EE11D
04CA    481D
04CC    831C181C DB 083H,1CH,18H,1CH,7AH,1BH,0D9H,1AH,36H,1AH
04D0    7A1BD91A
04D4    361A
04D6    9119EA18 DB 91H,19H,0EAH,18H,0E1H,18H,97H,17H,0ECH,16H
04DA    E1189717
04DE    EC16
04E0    3F169315 DB 3FH,16H,93H,15H,0E4H,14H,36H,14H,87H,13H
04E4    E4143614
04E8    8713
04EA    D9122B12 DB 0D9H,12H,2BH,12H,70H,11H,0D0H,10H,23H,10H
04EE    7011D010
04F2    2310
04F4    780FCE0E DB 78H,0FH,0CEH,0EH,26H,0EH,7EH,0DH,0D9H,0CH
04F8    260E7E0D
04FC    D90C
04FE    370C960B DB 37H,0CH,96H,0BH,0F8H,0AH,5DH,0AH,0CAH,09H
0502    F80A5D0A
```

```
0506      C409
0508      2E099C08 DB 2EH,09H,9CH,08H,0DH,08H,82H,07H,0FAH,06H
050C      0D088207
0510      FA05
0512      DA05F605 DB 0DAH,06H,0F6H,05H,73H,05H,04H,05H,91H,04H
0516      73050405
051A      9104
051E      2304B303 DB 23H,04H,0B3H,03H,56H,03H,0F7H,02H,9DH,02H
0520      5503F702
0524      9D02
0526      4902FA01 DB 49H,02H,0FAH,01H,0B0H,01H,6CH,01H,2CH,01H
052A      B0016C01
052E      2C01
0530      F400C200 DB 0F4H,00H,0C2H,00H,94H,00H,6DH,00H,42H,00H
0534      94006D00
0538      4200
053A      30001800 DB 30H,00H,18H,00H,0CH,00H,03H,00H,00H,00H
053E      0C000300
0542      0000
                   END
NO PROGRAM ERRORS
```


SYMBOL TABLE

```
* 01

A       0007     AMUA    4056     APPAR   0289     ARMAN   01AB
ASHIR   0394     B       0000     BASE    4065     BLADE   03AF
BOTHM   00A2     C       0001     CAMPA   02FD     CANAL   0256
CABIO   037E     CHINT   03CA     COALA   02C0  *  COSTA   0490
CHPPI   6003     D       0002     DATUM   4000     DECRE   0094
DELHI   0365     DERIV   0344     DIVIS   0395     DONE    0412
DOWER   00AC     DUSTL   039A     E       0003     ERASE   041C
FIFTH   4062     FINES   0148     FIRST   4059     FLAKE   0017
FORTH   4060     FRESH   0082     GANDT   01F2     GHOST   009B
GUDDI   021C     H       0004     HARAM   01A1     HOLDG   005C
IANGL   4058     IMPAN   02A2     INCR    008C     INTIC   4064
IONA    03FB     JANAK   0214     KARAM   01E5     KARZ    01DC
KEY     00CB     KISAN   0190     KORAR   0376     KUTAB   01AF
L       0005     LAMB    0021     LIMCA   02F4     LIME    010E
LIQUD   03FC     LOCK    00C5     LSUB    03F3     M       0006
MANDI   0290     MAXY    00D2     MINTO   03C4     MONA    028C
MSUB    0287     MULTI   0377     NAMAK   0197     NATH    016E
ORGIN   006F     PANAM   0242     PAFIL   0233     PEPSI   0341
PHULN   0133     PORTC   6002     PORTI   6001     PORTV   6000
POWER   029C     PSW     0006     PURI    0219     RAJNI   0358
RANY    035E     RIVER   0257     RST75   003C  *  SALT    0286
SAMPL   00A1     SCROL   031E     SECND   405C     SHIFT   0338
SIGN    0383     SIPPU   03FA     SOANG   0243     SOAP    03AC
SOHAN   024A     SOLO    00D7     SP      0006     STONE   02AB
SUBZI   020F     SUGAR   02B8     SONOM   0139     TANJE   0410
THIRD   405E     TRCCI   037A     TRIP1   041E     TRIP2   0426
TRIP3   042E     TUNES   015C     VANGL   4057     VBASE   4066
VDERI   4067     VENKT   006B     VISON   0387     WATER   0388
ZCAL    00E2     ZONE2   0306     ZONE3   0327
```

APPENDIX F


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                        ;-------------------------------------------------
                        ;   REAL TIME MICROPROCESSOR BASED PROGRAMME
                        ;   FOR QUADILATERAL CHRACTERISTIC DEVELOPED
                        ;   USING FUNDAMENTAL COMPONENT METHOD TAKING
                        ;   SAMPLES OVER ONE-HALF POWER CYCLE
                        ;-------------------------------------------------
                        ; ASSIGNMENT MEMORY LOCATION FOR VARIABLES
4000                     DATUM EQU 4000H   ;FOR STORING OF SAMPLES
6000                     PORTV EQU 6000H   ;PORT 1 FOR VOLTAGE SAMPLE
6001                     PORTI EQU 6001H   ;PORT 2 FOR CURRENT SAMPLE
4020                     FIRST EQU 4020H
4022                     SECND EQU 4022H
4024                     THIRD EQU 4024H
4026                     INTIC EQU 4026H
0500                     COSTE EQU 0500H
0520                     SINTE EQU 0520H
0540                     MITHN EQU 0540H
4027                     RESIS EQU 4027H    ;STORTING RESISTANCE
4028                     REACT EQU 4028H    ;STORING REACTANCE
4029                     VOLR  EQU 4029H ; VD COMPONENT OF VOLTAGE
402A                     VOLQ  EQU 402AH  ; VQ COMPONENT OF VOLTAGE
402B                     IOLR  EQU 402BH  ;ID COMPONENT OF CURRENT
402C                     IOLQ  EQU 402CH  ; IQ COMPONENT OF CURRENT
402D                     COUNT EQU 402DH
402E                     TIGER EQU 402EH
4030                     KOMAL EQU 4030H
4032                     JAKIN EQU 4032H    ;FAULTED SAMPLES
6002                     PORTC EQU 6002H    ;PORT C OF PPI
6003                     CWPPI EQU 6003H    ;CONTROL WORD OF PPI
0000                     ORG 0000H
0000      31FF42         LXI SP,42FFH
                        ;+++++++++++++++++++++++++++++++++++++++++++++++
                        ;INTIALISATION OF INPUTPORTS/OUTPUTPORTS AND
                        ;COUNTERS, LOADING OF CONSTANTS
                        ;++++++++++++++++++++++++++++++++++++++++++++++
0003      3E93           MVI A,93H
0005      320360         STA CWPPI
0008      3E00           MVI A,00H
000A      320260         STA PORTC
000D      3E00           MVI A,00H
000F      323040         STA KOMAL
0012      210040         LXI H,DATUM
0015      0E0C           MVI C,0CH
0017      3A0260        FLAKE: LDA PORTC
001A      1F             RAR
001B      DA2100         JC LAMB
001E      C31700         JMP FLAKE
0021      3A0060        LAMB : LDA PORTV
0024      CDEF02         CALL DELHI
0027      77             MOV M,A
0028      23             INX H
0029      3A0160         LDA PORTI
002C      CDEF02         CALL DELHI
002F      77             MOV M,A
0030      0D             DCR C
0031      CA8200         JZ JRESH
0034      C31700         JMP FLAKE
0037      00             NOP
0038      00             NOP
0039      00             NOP
003A      00             NOP
003B      00             NOP
003C      F5            RST75 :  PUSH PSW
003D      E5             PUSH H
003E      D5             PUSH D
003F      3A2640         LDA INTIC
0042      FE00           CPI 0H
0044      CA5C00         JZ HOLDG
0047      57             MOV D,A
0048      3E0C           MVI A,0CH
004A      92             SUB D
004B      210040         LXI H,DATUM
004E      5F             MOV E,A
004F      1600           MVI D,0H
```

```
0051   19       DAD D
0052   3A0060   LDA PORTV
0055   CDEF02   CALL DELHI
0058   77       MOV M,A
0059   C36B00   JMP VENKT
005C   3E0C     HOLDG: MVI A,0CH
005E   322640   STA INTIC
0061   210040   LXI H,DATUM
0064   3A0060   LDA PORTV
0067   CDEF02   CALL DELHI
006A   77       MOV M,A
006B   D1       VENKI: POP D
006C   E1       POP H
006D   F1       POP PSW
006E   C9       RET
006F   3A2640   ORGIN: LDA INTIC
0072   4F       MOV C,A
0073   3E0C     MVI A,0CH
0075   91       SUB C
0076   210040   LXI H,DATUM
0079   5F       MOV E,A
007A   1600     MVI D,0H
007C   19       DAD D
007D   1E00     MVI E,0H
007F   C38900   JMP CHEMS
                ;-------------------------------------------------------
                ;COLLECTION OF SAMPLES OF VOLTAGE AND CURRENT AND
                ;CYCLE BY CYCLE COMPARISON OF VOLTAGE SAMPLES AND
                ;REPLACING THE PREVIOUS BY LATEST SAMPLES OF V$ C.
                ;-------------------------------------------------------
0082   1E00     JRESH: MVI E,00H
0084   0E0C     FRESH: MVI C,0CH
0086   210040   LXI H,DATUM
0089   3A0260   CHEMS: LDA PORTC
008C   1F       RAR
008D   DA9300   JC CSOI
0090   C38900   JMP CHEMS
0093   CDB702   CSOI : CALL SAMP
0096   3E07     MVI A,07H
0098   BB       CMP E
0099   CAA700   JZ CALCU
009C   AF       XRA A
009D   79       MOV A,C
009E   FE00     CPI 00H
00A0   CA8400   JZ FRESH
00A3   23       INX H
00A4   C38900   JMP CHEMS
00A7   79       CALCU: MOV A,C
00A8   322640   STA INTIC
00AB   0606     MVI B,06H
00AD   B8       CMP B
00AE   DACE00   JC PENTR
00B1   90       SUB B
00B2   4F       MOV C,A
00B3   78       MOV A,B
00B4   91       SUB C
00B5   323040   STA KOMAL
00B8   3E0B     MVI A,0BH
00BA   91       SUB C
00BB   0C       INR C
00BC   113240   LXI D,JAKIN
00BF   CDF903   CALL BNZIR
00C2   3A3040   LDA KOMAL
00C5   4F       MOV C,A
00C6   3E00     MVI A,00H
00C8   CDF903   CALL BNZIR
00CB   C3DB00   JMP KRODI
00CE   80       PENTR: ADD B
00CF   47       MOV B,A
00D0   3E0B     MVI A,0BH
00D2   90       SUB B
00D3   0E07     MVI C,07H
00D5   113240   LXI D,JAKIN
00D8   CDF903   CALL BNZIR
```

```
                    ;-----------------------------------------
                    ;    CALCULATION OF VD
                    ;-----------------------------------------
00DB    213240      KRODI: LXI H,JAKIN
00DE    112D40       LXI D,COUNT
00E1    3E07         MVI A,07H
00E3    EB           XCHG
00E4    77           MOV M,A
00E5    D5           PUSH D    ;FIRST LOCATION WHERE FUNDAMENTAL COMPO STO
00E6    210000        LXI H,0000H
00E9    222040       SHLD FIRST
00EC    210005       LXI H,COSTE
00EF    CDFF02       CALL SUMMA
00F2    EB           XCHG
00F3    212940       LXI H,VOLR ; PLACE FOR STORING VD
00F6    73           MOV M,E
00F7    D1           POP D
                    ;-----------------------------------------
                    ;    CALCULATION OF VQ
                    ;-----------------------------------------
00F8    D5           PUSH D
00F9    212D40       LXI H,COUNT
00FC    3E07         MVI A,07H
00FE    77           MOV M,A
00FF    210000       LXI H,0000H
0102    222040       SHLD FIRST
0105    212005       LXI H,SINTE
0108    CDFF02       CALL SUMMA
010B    0650         MVI B,50H
010D    CD1504       CALL VISON
0110    AF           XRA A
0111    7A           MOV A,D
0112    17           RAL
0113    57           MOV D,A
0114    212A40        LXI H,VOLQ
0117    72           MOV M,D
0118    D1           POP D
                    ;-----------------------------------------
                    ;    CALCULATION OF ID
                    ;-----------------------------------------
0119    13           INX D
011A    D5           PUSH D
011B    212D40       LXI H,COUNT
011E    3ED7         MVI A,07H
0120    77           MOV M,A
0121    210000       LXI H,0000H
0124    222040       SHLD FIRST
0127    210005       LXI H,COSTE
012A    CDFF02       CALL SUMMA
012D    EB           XCHG
012E    212B40       LXI H, IOLR
0131    73           MOV M,E
0132    D1           POP D
                    ;-----------------------------------------
                    ;    CALCULATION OF IQ
                    ;-----------------------------------------
0133    212D40       LXI H,COUNT
0136    3ED7         MVI A,07H
0138    77           MOV M,A
0139    210000       LXI H,0000H
013C    222040       SHLD FIRST
013F    212005       LXI H,SINTE
0142    CDFF02       CALL SUMMA
0145    0650         MVI B,50H
0147    CD1504       CALL VISON
014A    AF           XRA A
014B    7A           MOV A,D
014C    17           RAL
014D    57           MOV D,A
014E    212C40       LXI H,IOLQ
0151    72            MOV M,D
                    ;
                    ;
```

```
                  ;
                  ;
                  ;--------------------------------------------------------
                  ;
                  ;      R=VD*ID+VQ*IQ/ ID**2 +IQ**2
                  ;
                  ;--------------------------------------------------------
0152   212940            LXI H,VDLR
0155   46         MOV B,M
                  ;
0156   23         INX H
0157   23         INX H
0158   4E         MOV C,M
0159   2B         DCX H
015A   E5         PUSH H
015B   CD9E03     CALL MULTI    ; TO CALCULATE VD*ID
015E   222E40     SHLD TIGER
0161   E1         POP H
0162   46         MOV B,M
0163   23         INX H
0164   23         INX H
0165   4E         MOV C,M
0166   E5         PUSH H
0167   CD9E03     CALL MULTI   ; TO CALCULATE VQ*IQ
016A   EB         XCHG
016B   2A2E40     LHLD TIGER
016E   19         DAD D
016F   222E40     SHLD TIGER ;SUM OF VD*ID+VQ*IQ IS STORED FIRST&FIRST
0172   E1         POP H
0173   46         MOV B,M     ; CONTENTS OF IDLQ (IQ) MOVED TO REG B
0174   48         MOV C,B
0175   2B         DCX H
0176   E5         PUSH H
0177   CD9E03     CALL MULTI   ;TO CALCULATE (IQ**2)
017A   222240     SHLD SECND
017D   E1          POP H
017E   46         MOV B,M
017F   48         MOV C,B
0180   CD9E03     CALL MULTI   ; TO CALCULATE (ID**2)
0183   EB         XCHG
0184   2A2240      LHLD SECND
0187   19         DAD D
0188   222240     SHLD SECND    ;SUM OF (ID**2+IQ**2)IS STORED AT SECN
                  ;--------------------------------------------------------
                  ;
                  ;      R=  TIGER / SECND
                  ;--------------------------------------------------------
                  ;     LHLD SECND    NOT REQUIRED
018B   EB         XCHG
018C   2A2E40     LHLD TIGER
018F   29         DAD H
0190   29         DAD H
0191   29         DAD H
0192   222040     SHLD FIRST
0195   2A2E40     LHLD TIGER
0198   29         DAD H
0199   4D         MOV C,L
019A   44         MOV B,H
019B   2A2040     LHLD FIRST
019E   09         DAD B
019F   4D         MOV C,L
01A0   44         MOV B,H
01A1   CD8004     CALL LISON
01A4   212740     LXI H,RESIS
01A7   71         MOV M,C
                  ; -------------------------------------------------------
                  ;      X=VQ*ID - VD*IQ/ID**2+IQ**2
                  ;--------------------------------------------------------
01A8   212A40     LXI H,VOLQ
01AB   46         MOV B,M
01AC   23         INX H
01AD   4E         MOV C,M
01AE   23         INX H
01AF   E5         PUSH H
```

```
01B0   CD9E03   CALL MULTI   ; TO CALCULATE VQ*ID
01B3   222440   SHLD THIRD
01B6   E1       POP H
01B7   46        MOV B,M
01B8   2B       DCX H
01B9   2B       DCX H
01BA   2B       DCX H
01BB   4E       MOV C,M
01BC   CD9E03   CALL MULTI   ; TO CALCULATE VD*IQ
01BF   CD7704   CALL TWOCM
01C2   EB       XCHG
01C3   2A2440   LHLD THIRD
01C6   19       DAD D
01C7   222440   SHLD THIRD
                ;-------------------------------------------------
                ;TO CALCULATE X =THIRD/SECND
                ;-------------------------------------------------
                ; LHLD THIRD NOT REQUIRED
01CA   29       DAD H
01CB   29       DAD H
01CC   29       DAD H
01CD   222040   SHLD FIRST
01D0   2A2440   LHLD THIRD
01D3   29       DAD H
01D4   4D       MOV C,L
01D5   44       MOV B,H
01D6   2A2040   LHLD FIRST
01D9   09       DAD B
01DA   4D       MOV C,L
01DB   44       MOV B,H
01DC   2A2240   LHLD SECND
01DF   EB       XCHG
01E0   CD8004   CALL LISON
01E3   212840   LXI H,REACT
01E6   71       MOV M,C
                ;-------------------------------------------------------
                ;RELAY LOGIC FOR QUADRILATERAL CHRACTERISTIC
                ;TO CHECK WHETHER R>0 OR NOT
                ;O CHECK WHETHER X > 0 OR NOT
                ;TO CHECK WHETHER R < R3 OR NOT
                ; TO CHECK WHETHER R < R2
                ; TO CHECK WHETHER R > R1 OR NOT
                ; TO CHECK WHETHER K4 > K2  K4=X/R-R2, K2=X1/R3-R2
                ; TO CHECK WHETHER K3 <K1 K3=X/R K1=X1/R1
                ; TO CHECK FOR ZONE1  ZONE2   ZONE3
                ;-------------------------------------------------------
01E7   AF       XRA A
01E8   212740   LXI H,RESIS
01EB   46       MOV B,M
01EC   23       INX H
01ED   4E       MOV C,M    ;REG B=RESISTANCE, REG C=REACTANCE
                ; TO CHECK WHETHER R > 0 OR NOT
01EE   78       MOV A,B
01EF   B7       ORA A
01F0   FA6F00   JM ORGIN
                ; TO CHECK WHETHER X> 0 OR NOT
01F3   79       MOV A,C
01F4   B7       ORA A
01F5   FA6F00   JM ORGIN
                ; TO CHECK WHETHER X< X1
01F8   161E     MVI D,1EH
01FA   BA       CMP D
01FB   D23B02   JNC ZONE2
                ;TO CHECK WHETHER R < R3 OR NOT
01FE   1611     MVI D,11H
0200   78       MOV A,B
0201   BA       CMP D
0202   D23B02   JNC ZONE2
                ; TO CHECK WHETHER R <R2
0205   160E     MVI D,0EH
0207   BA       CMP D
0208   D21402   JNC ARMAN
                ; TO CHECK WHETHER R >R1
020B   1603     MVI D,03H
```

```
020D    BA          CMP D
020E    DA2702      JC APPU
0211    C3C504      JMP TRIP1
                    ; TO CHECK WHETHER K4 ><2 AND CALCULATION OF K4
0214    AF          ARMAN: XRA A
0215    160E        MVI D,0EH
0217    78          MOV A,B
0218    92          SUB D
0219    47          MOV B,A
021A    CD5304      CALL DIVIS
021D    7A          MOV A,D
021E    160A        MVI D,0AH
0220    BA          CMP D
0221    DA6F00      JC ORGIN
0224    C3C504      JMP TRIP1
                    ; TO CHECK WHETHER K3 < K1
0227    AF          APPU : XRA A
0228    CD5304      CALL DIVIS
022B    7A          MOV A,D
022C    160A        MVI D,0AH
022E    BA          CMP D
022F    D23502      JNC LRESH
0232    C3C504      JMP TRIP1
0235    CAC504      LRESH: JZ TRIP1
0238    C38400      JMP FRESH
                    ;+++++++++++++++++++++++++++++++++++++++++++++++
                    ; TO CHECK FOR ZONE2 OPERATION
                    ;+++++++++++++++++++++++++++++++++++++++++++++++
                    ;TO CHECK WHETHER X < X1
023B    163C        ZONE2: MVI D,3CH
023D    79          MOV A,C
023E    BA          CMP D
023F    D27902      JNC ZONE3
                    ;TO CHECK WHETHER R<R3 OR NOT
0242    1614        MVI D,14H
0244    78          MOV A,B
0245    BA          CMP D
0246    D27902      JNC ZONE3
                    ;TO CHECK WHETHER R<R2 OR NOT
0249    160E        MVI D,0EH
024B    BA          CMP D
024C    D25802      JNC ZSMPP
                    ; TO CHECK WHETHER R>R1
024F    1606        MVI D,06H
0251    BA          CMP D
0252    DA6B02      JC QSTRI
0255    C3CD04      JMP TRIP2
                    ;TO CHECK WHETHER K4>K2 AND CALCULATION OF K4
0258    AF          ZSMPP: XRA A
0259    160E        MVI D,0EH
025B    78          MOV A,B
025C    92          SUB D
025D    47          MOV B,A
025E    CD5304      CALL DIVIS
0261    7A          MOV A,D
0262    160A        MVI D,0AH
0264    BA          CMP D
0265    DA6F00      JC ORGIN
0268    C3CD04      JMP TRIP2
                    ;TO CHECK WHETHER K3<K1
026B    AF          QSTRI: XRA A
026C    CD5304      CALL DIVIS
026F    7A          MOV A,D
0270    160A        MVI D,0AH
0272    BA          CMP D
0273    D26F00      JNC ORGIN
0276    C3CD04      JMP TRIP2
                    ;+++++++++++++++++++++++++++++++++++++++++++++++
                    ;TO CHECK FOR ZONE3 OPERATION
                    ;+++++++++++++++++++++++++++++++++++++++++++++++

                    ;TO CHECK WHETHER X < X1
0279    165A        ZONE3: MVI D,5AH
027B    79          MOV A,C
```

```
027C    BA        CMP D
027D    D26F00    JNC ORGIN
                 ;TO CHECK WHETHER R<R3 OR NOT
0280    1617      MVI D,17H
0282    78        MOV A,B
0283    BA        CMP D
0284    D26F00    JNC ORGIN
                 ;TO CHECK WHETHER R<R2 OR NOT
0287    160E      MVI D,0EH
0289    BA        CMP D
028A    D29602    JNC PSMMM
                 ; TO CHECK WHETHER R>R1
028D    1609      MVI D,09H
028F    BA        CMP D
0290    DAA902    JC MALOP
0293    C3D504    JMP TRIP3
                 ;TO CHECK WHETHER K4>K2 AND CALCULATION OF K4
0296    AF       PSMMM: XRA A
0297    160E      MVI D,0EH
0299    78        MOV A,B
029A    92        SUB D
029B    47        MOV B,A
029C    CD5304    CALL DIVIS
029F    7A        MOV A,D
02A0    160A      MVI D,0AH
02A2    BA        CMP D
02A3    DA6F00    JC ORGIN
02A6    C3D504    JMP TRIP3
                 ;TO CHECK WHETHER K3<K1
02A9    AF       MALOP: XRA A
02AA    CD5304    CALL DIVIS
02AD    7A        MOV A,D
02AE    160A      MVI D,0AH
02B0    BA        CMP D
02B1    D26F00    JNC ORGIN
02B4    C3D504    JMP TRIP3
                 ;-----------------------------------------------------
                 ;            SUBROUTINES
                 ;-----------------------------------------------------
02B7    46       SAMP : MOV B,M
02B8    3AD060    LDA PORTV
02BB    CDEF02    CALL DELHI
02BE    77        MOV M,A
02BF    23        INX H
02C0    3AD160    LDA PORTI
02C3    CDEF02    CALL DELHI
02C6    77        MOV M,A
02C7    2B        DCX H
                 ;TO COMPARE THE VOLTAGE SAMPLES
02C8    78        MOV A,B
02C9    56        MOV D,M
02CA    BA        CMP D
02CB    DAD102    JC LOCK
02CE    C3D302    JMP KEY
02D1    7A       LOCK : MOV A,D
02D2    50        MOV D,B
02D3    92       KEY  : SUB D
02D4    1605      MVI D,05H
02D6    BA        CMP D
02D7    DADD02    JC MAXY
02DA    C3EB02    JMP SOLD
02DD    AF       MAXY : XRA A
02DE    23        INX H
02DF    3E00      MVI A,00H
02E1    BB        CMP E
02E2    CAE602    JZ GHOST
02E5    1D        DCR E
02E6    AF       GHOST: XRA A
02E7    0D        DCR C
02E8    C3EE02    JMP JULLD
02EB    1C       SOLD : INR E
02EC    23        INX H
02ED    0D        DCR C
02EE    C9       JULLD:RET
```

```
                    ;++++++++++++++++++++++++++++++++++++++++++++++++
                    ;TO CONVRT THE OFFSET BINARY NUMBER
                    ;++++++++++++++++++++++++++++++++++++++++++++++++
02EF    37          DELHI: STC
02F0    3F           CMC
02F1    17           RAL
02F2    DAFB02       JC RAJNI
02F5    1F           RAR
02F6    F680         ORI 10000000B
02F8    C3FE02       JMP KORAR
02FB    1F          RAJNI: RAR
02FC    E67F         ANI 01111111B
02FE    C9          KORAR: RET
                    ;------------------------------------------------
                    ;  TO CALCULATE THE SUM OVER DATA WINDOW
                    ;------------------------------------------------
02FF    AF          SUMMA: XRA A
0300    46           MOV B,M
0301    23           INX H
0302    EB           XCHG
0303    4E           MOV C,M
0304    23           INX H
0305    23           INX H
0306    EB           XCHG
0307    E5           PUSH H
0308    D5           PUSH D
0309    78           MOV A,B
030A    B7           ORA A
030B    F21003       JP MONDI
030E    2F           CMA
030F    3C           INR A
0310    1603        MONDI: MVI D,03H
0312    BA           CMP D
0313    DA1D03       JC SURII
0316    AF           XRA A
0317    CD9E03       CALL MULTI
031A    C32003       JMP LURID
031D    CD5A03      SURII: CALL COSMJ
0320    EB          LURID: XCHG
0321    2A2040       LHLD FIRST
0324    19           DAD D
0325    222040       SHLD FIRST
0328    212D40       LXI H,COUNT
032B    7E           MOV A,M
032C    3D           DCR A
032D    C23303       JNZ PATIL
0330    C33903       JMP KIRTI
0333    77          PATIL: MOV M,A
0334    D1           POP D
0335    E1           POP H
0336    C3FF02       JMP SUMMA
0339    D1          KIRTI: POP D
033A    E1           POP H
033B    2A2040       LHLD FIRST
033E    7C           MOV A,H
033F    B7           ORA A
0340    FA4C03       JM BINDU
0343    7C           MOV A,H
0344    1F           RAR
0345    67           MOV H,A
0346    7D           MOV A,L
0347    1F           RAR
0348    6F           MOV L,A
0349    C35903       JMP RDBUR
034C    CD7704      BINDU: CALL TWOCM
034F    AF           XRA A
0350    7C           MOV A,H
0351    1F           RAR
0352    67           MOV H,A
0353    7D           MOV A,L
0354    1F           RAR
0355    6F           MOV L,A
0356    CD7704       CALL TWOCM
0359    C9          RDBUR:  RET
```

```
                        ;
                        ;
                        ;
                        ;
                        ;
                        ;+++++++++++++++++++++++++++++++++++++++++++++++++
                        ;TO CALCULATE THE PRODUCT OF COSINE TERMS
                        ;+++++++++++++++++++++++++++++++++++++++++++++++++
035A    C5              COSMU: PUSH B   ;REG B =CONSTANT REG C =SAMPLE VALUE
035B    78               MOV A,B
035C    B7               ORA A
035D    F26303           JP DVOS
0360    2F               CMA
0361    3C               INR A
0362    47               MOV B,A
0363    79              DVOS : MOV A,C
0364    B7               ORA A
0365    F26B03           JP VALM
0368    2F               CMA
0369    3C               INR A
036A    4F               MOV C,A
036B    78              VALM : MOV A,B
036C    FE00             CPI 00H
036E    CA9903           JZ SINGM
0371    79               MOV A,C
0372    FE00             CPI 00H
0374    CA9903           JZ SINGM
0377    210000           LXI H,0000H
037A    1600             MVI D,00H
037C    59               MOV E,C
037D    19              ARADN: DAD D
037E    05               DCR B
037F    CA8503           JZ MANJI
0382    C37D03           JMP ARADN
0385    C1              MANJI: POP B
0386    AF               XRA A
0387    78               MOV A,B
0388    A9               XRA C
0389    FA8F03           JM GUDWR
038C    C39D03           JMP NANKA
038F    7D              GUDWR: MOV A,L
0390    2F               CMA
0391    6F               MOV L,A
0392    7C               MOV A,H
0393    2F               CMA
0394    67               MOV H,A
0395    23               INX H
0396    C39D03           JMP NANKA
0399    C1              SINGM: POP B
039A    210000           LXI H,0000H
039D    C9              NANKA: RET
                        ;-------------------------------------------------
                        ; MULTIPLICATION  REG B=CONSTANT REG C=SAMPLE
                        ;-------------------------------------------------
039E    C5              MULTI: PUSH B
039F    78               MOV A,B
03A0    E680             ANI 10000000B
03A2    FE00             CPI 00H
03A4    CAAB03           JZ  GARG
03A7    78               MOV A,B
03A8    2F               CMA
03A9    3C               INR A
03AA    47               MOV B,A
03AB    79              GARG: MOV A,C
03AC    E680             ANI 10000000B
03AE    FE00             CPI 00H
03B0    CAB703           JZ ABHA
03B3    79               MOV A,C
03B4    2F               CMA
03B5    3C               INR A
03B6    4F               MOV C,A
03B7    78              ABHA : MOV A,B
03B8    FE00             CPI 00H
03BA    CAF403           JZ RITA
```

```
03BD   79       MOV A,C
03BE   FE00     CPI 00H
03C0   CAF403   JZ RITA
03C3   78       MOV A,B;REGA=MULTIPLIER REG C=MULTIPLICANT RES IN H-.
03C4   210000   LXI H,00H
03C7   1608     MVI D,08H
03C9   44       MOV B,H
03CA   0F       CASIO: RRC
03CB   D2CF03   JNC SIGN
03CE   09       DAD B
03CF   15       SIGN : DCR D
03D0   CAE003   JZ ASHTR
03D3   5F       MOV E,A
03D4   79       MOV A,C
03D5   37       STC
03D6   3F       CMC
03D7   17       RAL
03D8   4F       MOV C,A
03D9   78       MOV A,B
03DA   17       RAL
03DB   47       MOV B,A
03DC   7B       MOV A,E
03DD   C3CA03   JMP CASIO
03E0   C1       ASHTR: POP B
03E1   AF       XRA A
03E2   78       MOV A,B
03E3   A9       XRA C
03E4   FAEA03            JM KUWAT
03E7   C3F803   JMP ARABN
03EA   7D       KUWAT: MOV A,L
03EB   2F       CMA
03EC   6F       MOV L,A
03ED   7C       MOV A,H
03EE   2F       CMA
03EF   67       MOV H,A
03F0   23       INX H
03F1   C3F803   JMP ARABN
03F4   C1       RITA : POP B
03F5   210000   LXI H,0000H
03F8   C9       ARABN: RET
                ;++++++++++++++++++++++++++++++++++++++++++++
                ;TO DERIVE SINGLE PHASE RELAYING QUATITIES
                ;++++++++++++++++++++++++++++++++++++++++++++=.
03F9   214005   BNZIR :LXI H,MITHN
03FC   85       ADD L
03FD   6F       MOV L,A
03FE   7E       MOV A,M
03FF   210040   LXI H,DATUM
0402   85       ADD L
0403   6F       MOV L,A
0404   7E       ROMA: MOV A,M
0405   EB       XCHG
0406   77       MOV M,A
0407   23       INX H
0408   EB       XCHG
0409   23       INX H
040A   7E       MOV A,M
040B   EB       XCHG
040C   77       MOV M,A
040D   23       INX H
040E   EB       XCHG
040F   23       INX H
0410   0D       DCR C
0411   C20404   JNZ ROMA
0414   C9       RET   ;
                ;+++++++++++++++++++++++++++++++++++
                ;      16BIT DIVISON SUBROUTINE
                ;++++++++++++++++++++++++++++++++++++++++++++++++
0415   E5       VISON: PUSH H
0416   7C       MOV A,H
0417   E680     ANI 10000000B
0419   FE00     CPI 00H
041B   CA2504   JZ RINKU
041E   7C       MOV A,H
```

```
041F    2F        CMA
0420    67        MOV H,A
0421    7D        MOV A,L
0422    2F        CMA
0423    6F        MOV L,A
0424    23        INX H
0425    1600      RINKU: MVI D,00H
0427    1E00      MVI E,00H
0429    7B        CHINT: MOV A,E
042A    FE08      CPI 08H
042C    CA3E04    JZ MINTO
042F    29        DAD H
0430    1C        INR E
0431    7A        MOV A,D
0432    07        RLC
0433    57        MOV D,A
0434    7C        MOV A,H
0435    90        SUB B
0436    DA3B04    JC BAWA
0439    14        INR D
043A    67        MOV H,A
043B    C32904    BAWA :  JMP CHINT
043E    7C        MINTO: MOV A,H
043F    07        RLC
0440    B8        CMP B
0441    DA4504    JC BANTI
0444    14        INR D
0445    E1        BANTI: POP H
0446    7C        MOV A,H
0447    E680      ANI 10000000B
0449    FE00      CPI 00H
044B    CA5204    JZ NEEL
044E    7A        MOV A,D
044F    2F        CMA
0450    57        MOV D,A
0451    14        INR D
0452    C9        NEEL : RET
                  ;---------------------------------------------------
                  ;    DIVISON
                  ;---------------------------------------------------
0453    AF        DIVIS: XRA A
0454    78        MOV A,B
0455    69        MOV L,C
0456    2600      MVI H,00H
0458    54        MOV D,H
0459    5C        MOV E,H
045A    7B        DUSTL: MOV A,E
045B    FE08      CPI 08H
045D    CA6F04    JZ BLADE
0460    29        DAD H
0461    1C        INR E
0462    7A        MOV A,D
0463    07        RLC
0464    57        MOV D,A
0465    7C        MOV A,H
0466    90        SUB B
0467    DA6C04    JC SOAP
046A    14        INR D
046B    67        MOV H,A
046C    C35A04    SOAP : JMP DUSTL
046F    7C        BLADE : MOV A,H
0470    07        RLC
0471    B8        CMP B
0472    DA7604    JC WATER
0475    14        INR D
0476    C9        WATER: RET
                  ;-----------------------------------------;
                  ;    TWOCM
                  ;-----------------------------------------;
0477    AF        TWOCM: XRA A
0478    7D        MOV A,L
0479    2F        CMA
047A    6F        MOV L,A
047B    7C        MOV A,H
```

```
047C    2F       CMA
047D    67       MOV H,A
047E    23       INX H
047F    C9       RET
                 ;
                 ;
                 ;
                 ;
                 ;===============================================
                 ;16 BITS DIVISON SUBROUTINE REG B-C PAIR INTIALLY CON
                 ;REG PAIR  D-E CONTAINS DIVISOR AND IN THE END REG B-
                 ;QUOTIENT, REG D-E CONTAINS REMAINDER
                 ;===============================================
0480    210000   LTSON: LXI H,0000H
0483    D5        PUSH D
0484    7A        MOV A,D
0485    2F        CMA
0486    57        MOV D,A
0487    7B        MOV A,E
0488    2F        CMA
0489    5F        MOV E,A
048A    13        INX D
048B    3E11      MVI A,17D
048D    E5       LINTO: PUSH H
048E    19        DAD D
048F    D29304    JNC RHINT
0492    E3        XTHL
0493    E1       RHINT: POP H
0494    F5        PUSH PSW
0495    79        MOV A,C
0496    17        RAL
0497    4F        MOV C,A
0498    78        MOV A,B
0499    17        RAL
049A    47        MOV B,A
049B    7D        MOV A,L
049C    17        RAL
049D    6F        MOV L,A
049E    7C        MOV A,H
049F    17        RAL
04A0    67        MOV H,A
04A1    F1        POP PSW
04A2    3D        DCR A
04A3    C28D04    JNZ LINTO
                 ;SHIFT REMAINDER RIGHT & RETURN IN H-L
04A6    B7        ORA A
04A7    7C        MOV A,H
04A8    1F        RAR
04A9    67        MOV H,A
04AA    7D        MOV A,L
04AB    1F        RAR
04AC    6F        MOV L,A
04AD    29        DAD H
04AE    D1        POP D
04AF    7D        MOV A,L
04B0    BB        CMP E
04B1    DABC04    JC MSUB
04B4    7C        MOV A,H
04B5    BA        CMP D
04B6    DAC404    JC MONA
04B9    C3C304    JMP DIPPU
04BC    AF       MSUB : XRA A
04BD    7C        MOV A,H
04BE    3D        DCR A
04BF    BA        CMP D
04C0    DAC404    JC MONA
04C3    03       DIPPU: INX B
04C4    C9       MONA : RET ; REG B-C=QUOTIENT
                 ;-----------------------------------------------
                 ;                 TRIP
                 ;-----------------------------------------------
04C5    3E80     TRIP1 :MVI A,80H
04C7    320260    STA PORTC
04CA    C3C504    JMP TRIP1
```

```
04CD    3E20        TRIP2: MVI A,20H
04CF    320260       STA PORTC
04D2    C3CD04       JMP TRIP2
04D5    3E40        TRIP3: MVI A,40H
04D7    320260       STA PORTC
04DA    C3D504       JMP TRIP3
04DD    76           HLT
0520                 ORG SINTE
0520    00232300     DB 00H,23H,23H,00H,-23H,-23H
0524    DDDD00
0500                 ORG COSTE
0500    FFFF0102     DB -1H,-1H,1H,2H,1H,-1H,-1H
0504    01FFFF
0540                 ORG MITHN
0540    00020406     DB 00H,02H,04H,06H,08H,0AH,0CH,0EH,10H,12H,14H,16H
0544    080A0C0E
0548    10121416
                     END
NO PROGRAM ERRORS
```


SYMBOL TABLE

* 01

A	0007	ABHA	03B7	APPU	0227	ARABN	03F8
ARADN	037D	ARMAN	0214	ASHTR	03E0	B	0000
BANTI	0445	BAWA	043B	BINDU	034C	BLADE	046F
BNZIR	03F9	C	0001	CALCU	00A7	CASIO	03CA
CHEMS	0089	CHINT	0429	COSMU	035A	COSTE	0500
COUNT	402D	CSOI	0093	CWPPI	6003	D	0002
DATUM	4000	DELHI	02EF	DIPPU	04CB	DIVIS	0453
DUSTL	045A	DVDS	0363	E	0003	FIRST	4020
FLAKE	0017	FRESH	0084	GARG	03AB	GHOST	02E6
GUDWR	038F	H	0004	HOLOG	005C	INTIC	4026
IOLQ	402C	IOLR	402B	JAKIN	4032	JRESH	0082
JULLD	02EE	KEY	02D3	KIRTI	0339	KOMAL	4030
KORAR	02FE	KRODI	00DB	KUWAT	03EA	L	0005
LAMB	0021	LINTO	048D	LISON	0480	LOCK	02D1
LRESH	0235	LURID	0320	M	0006	MALOP	02A9
MANJI	0385	MAXY	02DD	MINTO	043E	MITHN	0540
MONA	04C4	MONDI	0310	MSUB	04BC	MULTI	039E
NANKA	039D	NEEL	0452	ORGIN	006F	PATIL	0333
PENTR	00CE	PORTC	6002	PORTI	6001	PORTV	6000
PSMMM	0296	PSW	0006	OSTRI	026B	RAJNI	02FB
RDBUR	0359	REACT	4028	RESIS	4027	RHINT	0493
RINKU	0425	RITA	03F4	ROMA	0404	RST75	003C *
SAMP	0287	SECND	4022	SIGN	03CF	SINGM	0399
SINTE	0520	SOAP	046C	SOLO	02EB	SP	0006
SUMMA	02FF	SURII	031D	THIRD	4024	TIGER	402E
TRIP1	04C5	TRIP2	04CD	TRIP3	04D5	TWOCM	0477
VALM	036B	VENKT	006B	VISON	0415	VOLQ	402A
VOLR	4029	WATER	0476	ZONE2	023B	ZONE3	0279
ZSMPP	0258						